Chapter 4
U.S. and International Research and Development: Funds and Alliances

Highlights

National R&D Support

- **Since 1994, research and development (R&D) in the United States has risen sharply, from $169.2 billion to an estimated $265 billion in 2000.** In real terms (adjusting for inflation), this rise reflects an increase of $71 billion in 1996 dollars, which was the greatest real increase in R&D for any six-year period in the nation's history.
- **Private industry, which provided 68 percent of total R&D funding in 2000, pays for most of the nation's R&D.** Private industry itself used nearly all (98 percent) of these funds in performing its own R&D; most (71 percent) of the funds were used to develop products and services rather than to conduct research.
- **Federal R&D support, in absolute terms, expanded between 1980 and 2000, from $30 billion to $70 billion, which, after inflation, amounted to a small real growth rate of 1 percent per year.** In 1980, Federal R&D support accounted for 47 percent of the nation's total R&D effort. By 2000, Federal sources accounted for considerably less (26 percent) of the U.S. R&D total.
- **In fiscal year (FY) 2001, the Department of Defense (DOD) will obligate the most funds among Federal agencies for R&D support—$36 billion or 45 percent of all Federal R&D obligations.** The agency obligating the second largest amount in R&D support is the Department of Health and Human Services with $19 billion, followed by the National Aeronautics and Space Administration with $10 billion, the Department of Energy with $7 billion, and the National Science Foundation with $3 billion.
- **The budget allocation for health-related R&D increased dramatically between FY 1982 and FY 2001 with an average real annual growth rate of 5.8 percent.** As a result, health-related R&D rose from approximately one-quarter of the Federal, nondefense, R&D budget allocation in FY 1982 to nearly one-half by FY 2001.

National R&D Performance

- **Industry performed the largest share of the nation's R&D—75 percent.** Universities and colleges performed 11 percent, and the Federal Government performed 7 percent. Federally Funded Research and Development Centers (FFRDCs), which are administered by various industrial, academic, and nonprofit institutions, accounted for an additional 4 percent, and other nonprofit organizations accounted for 3 percent.
- **From 1994 to 2000, R&D performed by industry (including their FFRDCs) grew at a remarkable rate of 7 percent per year in real terms.** In contrast, Federal intramural research over the same period increased by less than 1 percent per year in real terms.
- **In the industrial sector in 1999, computer and electronic products alone accounted for 20 percent of all industrial R&D and 15 percent of the nation's total R&D.** Computers and electronics accounted for $36 billion in performance R&D, which exceeded the total amount of R&D performed by all universities and colleges and their administered FFRDCs combined ($34 billion). The next largest industrial sector, transportation equipment, also performed $34 billion in R&D in 1999. The chemicals sector performed $20 billion in R&D, as did trade, a nonmanufacturing sector. Another nonmanufacturing sector, information, performed $15 billion in R&D.
- **A recent NSF survey has led to upward revisions in R&D performance estimates for the nonprofit sector.** R&D performance by nonprofit organizations is expected to reach $9 billion in 2000, reflecting an average annual growth of 6 percent in real terms since 1990.
- **In 1999, California had the highest level of R&D expenditures within its borders, $48 billion.** The six states with the highest levels of R&D expenditures, California, Michigan, New York, Texas, Massachusetts, and Pennsylvania (in descending order), accounted for approximately one-half of the entire national effort.
- **The nation spent $48 billion on basic research in 2000, $55 billion on applied research, and $162 billion on development.** These totals are the result of continuous increases over several years. Since 1980 they reflect, in real terms, a 5 percent annual increase for basic research, a 4 percent increase for applied research, and a 4 percent increase for development.

Federal R&D Tax Credit

- **In 1998, 9,800 corporate tax returns claimed $5.2 billion in research and experimentation (R&E) credits, up 18.4 percent from 1997 claims.** The unusual doubling of the credit over 1996–97 followed a 12-month gap in the credit.
- **The tax credit claims were equivalent to $3.3 billion (4.6 percent) of Federal R&D outlays in FY 1998.** Although R&E claims data for tax year 2000 are not available, the credit generated an estimated outlay equivalent of $2.5 billion, or 3.4 percent of Federal R&D outlays in FY 2000.

Domestic R&D Collaborations

- **More than 800 research joint ventures (RJVs) were formed in the United States from 1985 to 2000 (including 39 in 2000) according to filings required by the National Cooperative Research and Production Act (NCRPA).** New filings peaked in 1995 at 115 after increasing successively since 1986. These research collaborations involved more than 4,200 unique businesses and organizations, of which more than 3,000 (about three-fourths) were U.S.-based.

- **Half of the RJVs over the entire 1985–2000 period involved companies in three industries: electronic and electrical equipment, communications, and transportation equipment.** Universities participated in 15 percent of all RJVs, and 11 percent had at least one Federal laboratory member.
- **In 2000, Federal agencies involved in R&D and technology transfer activities reported 4,209 invention disclosures, 2,159 patent applications, and 1,486 patents issued.** Since fiscal year 1997, a total of 5,655 patents have been issued to federal agencies.
- **A total of 2,924 Cooperative Research and Development Agreements (CRADAs) involving 10 Federal agencies and laboratories were active in 2000.** The largest participants by far are DOD laboratories (1,364 active CRADAS or 47 percent of the total) and DOE (687 or 23 percent). The number of active CRADAs increased rapidly in the early- and mid-1990s, reached a peak of 3,688 in fiscal year 1996, and stabilized around 3,000 since then.
- **The Small Business Innovation Research (SBIR) program, designed to increase small firms' participation in Federal R&D activity, awarded a total of $1.1 billion in R&D money to approximately 4,600 projects in 1999.** Ten agencies participated in the program in FY 1999. DOD and HHS accounted for $514 million (47 percent) and $314 million (29 percent), respectively, of SBIR funding.

International Comparisons of National R&D Trends

- **The United States accounts for approximately 44 percent of total R&D expenditures in all Organisation for Economic Co-operation and Development (OECD) countries combined. R&D investments in the United States continue to outdistance, by more than 150 percent, R&D investments made by Japan, the second largest performer.** The United States spent more on R&D activities in 1999 than did all other "group of seven" (G-7) countries (Canada, France, Germany, Italy, Japan, and the United Kingdom) combined. In 1998, total nondefense R&D spending in those six countries was slightly more (6 percent) than nondefense R&D spending in the United States.
- **The ratio of R&D spending to gross domestic product (GDP) is one of most widely used indicators of a country's commitment to growth in scientific knowledge and technology development.** As a result of a worldwide slowing in R&D spending during the early 1990s, the latest R&D/GDP ratio for most G-7 countries is no higher now than it was a decade ago. The United States ranked fifth among OECD countries in terms of reported R&D/GDP ratios for the 1996–98 period (2.7 percent). Sweden leads all countries for GDP devoted to R&D (3.7 percent), followed by Japan (3.0 percent), Finland (2.9 percent), and Switzerland (2.7 percent).
- **Although reported data by character of the work are somewhat sparse, development spending (typically performed by industry) accounts for the largest R&D share in most countries (usually approximately 60 percent of the total).** Relative to shares reported in other countries, basic research spending in the United States (16 percent of its R&D total) is less than the shares reported for France and Italy (25 and 22 percent, respectively) but higher than reported for Japan and South Korea (12 and 14 percent, respectively). Basic research accounts for 16 percent of Russia's R&D total.
- **Structural R&D shifts are under way in many G-7 and other OECD countries.** As an indication of an overall pattern of increased university-firm interactions, the proportion of academic R&D funding from industry sources (for G-7 countries combined) climbed from 2.5 percent of the academic R&D total in 1981 to 5.4 percent in 1990 and to 6.4 percent in 1998.
- **Even though most OECD countries perform R&D in support of multiple industry sectors, the distribution of the industrial R&D effort in the United States is among the most widespread and diverse.** This circumstance may indicate a national inclination and ability to become globally competitive in numerous industries rather than specialize in a few industries or niche technologies. Within countries, the electrical equipment sector often is among the largest performers of the industrial R&D effort, accounting for 20 percent or more of the industry R&D total. In addition to the United States, numerous countries report substantial increases in their service sector R&D expenditures during the past 25 years.
- **The most noteworthy trend among G-7 and other OECD countries has been the relative decline in government R&D funding.** In 1998, 31 percent of all OECD R&D funds was derived from government sources—down considerably from the 41 percent share reported for 1988. In aggregate terms, this change reflects a decline in industrial reliance on government funds for R&D performance. In 1988, the government provided 20 percent of the funds used by industry conducting R&D within OECD countries. By 1998, the government's share of the industry R&D total had fallen by one-half, to 10 percent of the total.
- **Government R&D priorities also have shifted somewhat among OECD countries during the past decade.** As a result of relative decreases not only in the United States but also in the United Kingdom and France, the national defense share of the government R&D total in all OECD countries combined declined from 43 percent in 1988 to 30 percent in 1998.
- **Among nondefense objectives, government R&D spending shares also changed somewhat during the 1988–98 period: government R&D shares have increased most for health and the environment and for various nondirected R&D (including many basic research) activities.**

Conversely, the relative share of government R&D support provided for economic development programs (which include the promotion of agriculture, fisheries and forestry, industry, infrastructure, and energy) has declined considerably, from 31 percent of the combined OECD governments' nondefense total in 1981 to 23 percent in 1998.

International R&D Alliances

- **In 2000, 574 new technology or research alliances worldwide were reported in six major sectors: information technology (IT), biotechnology, advanced materials, aerospace and defense, automotive, and nonbiotechnology chemicals.** The vast majority involved companies from the United States, Japan, and countries of Western Europe. The number of new alliances reported in this international database between 1990 and 2000 (6,477) was nearly twice the number formed during the previous 10-year period, 1980–89 (3,826). The 1990–2000 total includes 2,658 (41 percent) alliances involving exclusively U.S.-owned companies.
- **The share of biotechnology partnerships reached an all-time high of 35 percent in 2000 (199 of 574), continuing an increasing trend that began in 1991.** This is the first year that biotechnology alliances have outnumbered IT partnerships.
- **The United States and Europe were prime locales for biotechnology alliances during the 1990s.** Of the 1,500 biotechnology alliances in the past decade, 41 percent involved only companies in the United States and another 34 percent involved pairings of U.S. companies and European companies.

International Industrial R&D Investments

- **As of 1998, the latest year for which data are available, 715 R&D facilities in the United States were operated by 375 foreign-owned companies, including 251 (35 percent) owned by Japanese parent companies.** Other countries with significant presence were Germany with 107 facilities (15 percent), and the United Kingdom with 103 facilities (14 percent). On the other hand, by 1997 U.S. companies had established at least 186 R&D facilities overseas.
- **R&D spending by U.S. affiliates of foreign companies in the United States increased 28 percent in 1997–98, from $17 billion to $22 billion, the largest single-year increase since 1990.** When combined with the $15 billion spent abroad on R&D by U.S.-based companies, this yields a "net inflow" of R&D expenditures of more than $7 billion, compared with $3 billion a year earlier.
- **Chemical and computer and electronic product manufacturing had the largest single-industry shares of foreign R&D spending in the United States in 1998 (33 and 20 percent, respectively).** They include the largest subsectors attracting foreign R&D funding: pharmaceuticals and communications equipment. More than one-half of the R&D performed on chemicals and pharmaceuticals by foreign-owned subsidiaries in the United States is performed by Swiss and German units.
- **Of the $15 billion spent abroad in R&D by the nation's majority-owned foreign affiliates in 1998, more than two-thirds took place in five countries: Canada, France, Germany, Japan, and the United Kingdom.** Approximately three-fourths of all R&D performed overseas is in four manufacturing sectors: transportation equipment (30 percent), chemicals (27 percent), electronic equipment (8 percent), and industrial machinery (7 percent). R&D performed in chemicals and pharmaceuticals overseas reached $4 billion in 1998; nearly $1 billion was located in the United Kingdom. Of the $4.5 billion in automotive and other transportation equipment research performed overseas, 42 percent was located in Germany, and 21 percent in Canada.
- **Within the IT sector, foreign R&D in the U.S. emphasizes the manufacturing component, whereas R&D by foreign affiliates of U.S. companies emphasizes the services component.** The share of information services in R&D spending abroad (8.3 percent) was five times larger than that industry's share in foreign R&D (1.5 percent) in 1998. On the other hand, computer and electronic product manufacturing accounted for 20 percent of total foreign R&D in the United States, or double its 10 percent share in R&D funds spent abroad.
- **The Industrial Globalization R&D (IGRD) index, defined as the average of foreign and overseas R&D spending shares for a given industry, is an indicator of the degree of internationalization of R&D spending.** By this measure, chemical R&D flows exhibit the highest degree of internationalization (IGRD index of 25), followed by transportation equipment (IGRD index of 19) and computer manufacturing (IGRD index of 15).

Introduction

Chapter Overview

Research and development (R&D) is widely recognized as being key to economic growth, along with factors such as "education, training, production engineering, design, and quality control" (Freeman and Soete 1999). Although R&D expenditures never have exceeded 3 percent of the U.S. economy and the precise effects of R&D have been difficult to measure (or sometimes even identify), scientific and government communities continue to study R&D expenditures to understand and improve the patterns of technological change that occur in the economy and society. As Rosenberg (1994) expressed:

> Science will often provide the capability to acquire information about technological alternatives that we do not presently possess, but *science does not make the acquisition of this information cost less.*…One valuable perspective on the cost of acquiring information is offered by the available data on R&D expenditures. These data are additionally valuable in showing the extent to which the generation and diffusion of knowledge has become an economic activity.

R&D decisionmaking—how much money different organizations spend and the areas of science or engineering on which they spend it—is critical to the future of the U.S. economy and national well-being. For this reason, the United States and many other nations collect extensive R&D expenditure data that are disseminated worldwide for study by analysts in a wide variety of fields.

In addition to indicating the direction of technological change, R&D expenditure data also measure the level of economic purchasing power that has been devoted to R&D projects compared with other economic activities. Industrial (private sector) funding of R&D, for example, may be considered an economic metric of how important R&D is to companies, since companies could easily devote those same funds to other business activities. Likewise, government support for R&D reflects governmental and societal commitment to scientific and engineering advancement, an objective that must compete for dollars against other functions served by discretionary government spending. The same basic notion is true for the other sectors that fund R&D: universities, colleges, and other nonprofit organizations.

Total R&D expenditures, therefore, reveal the perceived economic importance of R&D relative to all other economic activities. Because institutions invest in R&D without knowing the final outcome (if they did, then it would not be R&D), the amount they devote is based on their perception, rather than on their absolute knowledge, of R&D's value. Such information about R&D's perceived relative value is also extremely useful for economic decisionmaking. Of course, R&D data alone are not enough to accurately analyze the future growth of a field of study or an industrial sector, but they represent important input into such analyses. In addition to the total amount of R&D expenditures, a policy variable of equal importance is the composition of this R&D (Tassey 1999). Both econometric work and case studies have demonstrated the different but equally important roles of each phase of the R&D life cycle. Over this cycle, different classes of R&D funders and performers rise in importance, then give way to others. The availability and timeliness of these different participants determine the success or failure of technology-intensive industries relative to foreign competitors. This chapter is designed to provide a broad understanding of the nature of R&D expenditures and the implications of R&D expenditures for science and technology (S&T) policy.

Chapter Organization

This chapter is organized into five major parts that examine trends in R&D expenditures. The first and second parts look into R&D funded and performed solely in the United States. The first part contains information on economic measures of R&D spending in the United States and trends in financial support for R&D, giving particular attention to direct Federal R&D support as well as indirect fiscal measures to stimulate R&D growth. The second part describes trends in total R&D performance in the United States; areas addressed include industrial R&D performance and R&D performance by geographic location, character of work, and field of science.

The third part summarizes available information on R&D collaborations, alliances, and partnerships. It contains sections on intersector and intrasector R&D partnerships and alliances, including private-private, public-private, and public-public collaborations that have formed both domestically and internationally.

The fourth part compares R&D trends across nations. It contains sections on total and nondefense R&D spending, ratios of R&D to gross domestic product (GDP) among different nations, international R&D funding by performer and source (including information on industry subsectors and academic science and engineering fields), the character of R&D efforts (or R&D efforts separated into basic research, applied research, and development components), and international comparisons of government R&D priorities and tax policies.

The fifth part provides statistics on international R&D investment flows. It contains a review of the U.S. international R&D investment balance, discusses patterns in overseas and foreign R&D performed in the United States in terms of expenditures and facility placement, and offers a new Industry Globalization R&D (IGRD) index as a way of measuring which industries have adopted the most internationalized approach in their R&D activities.

R&D Support in the United States

Since 1994, R&D in the United States has risen sharply, from $169.2 billion to an estimated $264.6 billion in 2000.[1] In real terms (adjusting for inflation), this rise has been from $176.2 billion to $247.5 billion in constant 1996 dollars, reflecting an annual real growth rate of 5.8 percent. The increase of $71.3 billion 1996 dollars between 1994 and 2000 is the greatest single real increase for any six-year period in

[1] At the time this report was written, estimated data for 2000 were the latest figures available on R&D expenditures.

the history of the R&D data series, which began in 1953. (See figure 4-1.) The consistent pattern of R&D growth is noteworthy, implying a broad-based, increased interest in the promotion of R&D activities. See sidebar, "Definitions of Research and Development."

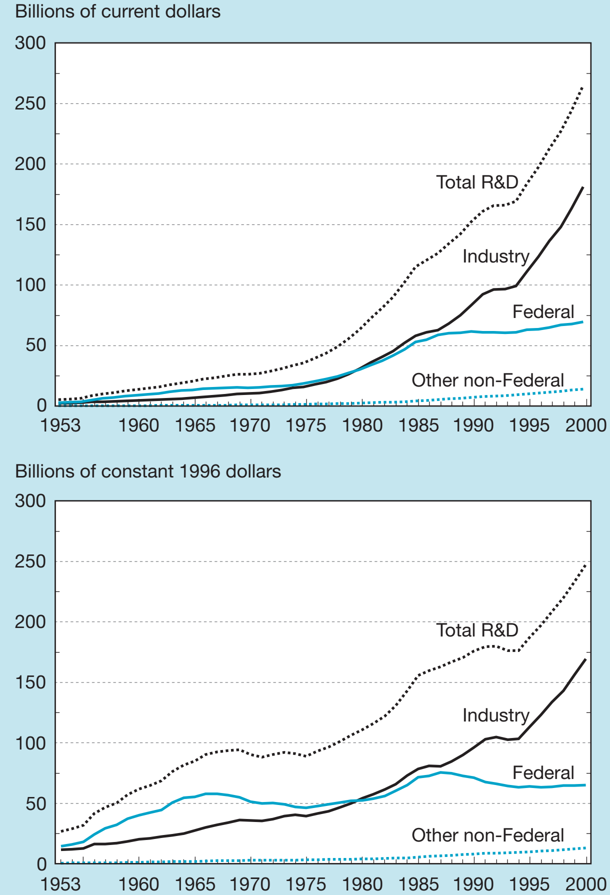
By comparison, gross domestic product (GDP), the main measure of the nation's total economic activity, grew in real terms by 4 percent per year between 1994 and 2000. Thus, R&D has generally been outpacing the growth of the overall economy since 1994. As a result, R&D as a proportion of GDP has risen from 2.40 percent in 1994 to 2.66 percent in 2000.

Organizations that conduct R&D often receive outside funding; conversely, organizations that fund R&D often do not perform all R&D themselves. Therefore, in any discussion of the nation's R&D, a distinction must be made between where the money came from originally (R&D expenditures characterized by source of funds) and where the R&D is actually being performed (R&D expenditures categorized by performer).

Private industry, which provided 68.4 percent ($181.0 billion) of total R&D funding in 2000, pays for most of the nation's R&D. Private industry itself used nearly all of these funds (98.1 percent) in performing its own R&D; most of the funds (70.9 percent) were used to develop products and services rather than to conduct research. In 2000, the Federal Government provided the second largest share of R&D funding, 26.3 percent ($69.6 billion), and the other sectors of the economy (i.e., state governments, universities and colleges, and nonprofit institutions) contributed the remaining 5.3 percent ($14.0 billion). (See figures 4-1, 4-2, and 4-3; and text table 4-1.)

Briefly, in terms of R&D performance—and discussed in greater detail below—industry in 2000 accounted for an even larger share of the total (74.6 percent), followed by universities and colleges (11.4 percent) and the Federal Government (7.2 percent). Federally Funded Research and Development Centers (FFRDCs), which are administered by various industrial, academic, and nonprofit institutions, accounted for an additional 3.5 percent, and other nonprofit organizations accounted for 3.3 percent. (See text table 4-1.)[2]

Figure 4-1.
National R&D funding, by source: 1953–2000



See appendix tables 4-5 and 4-6.

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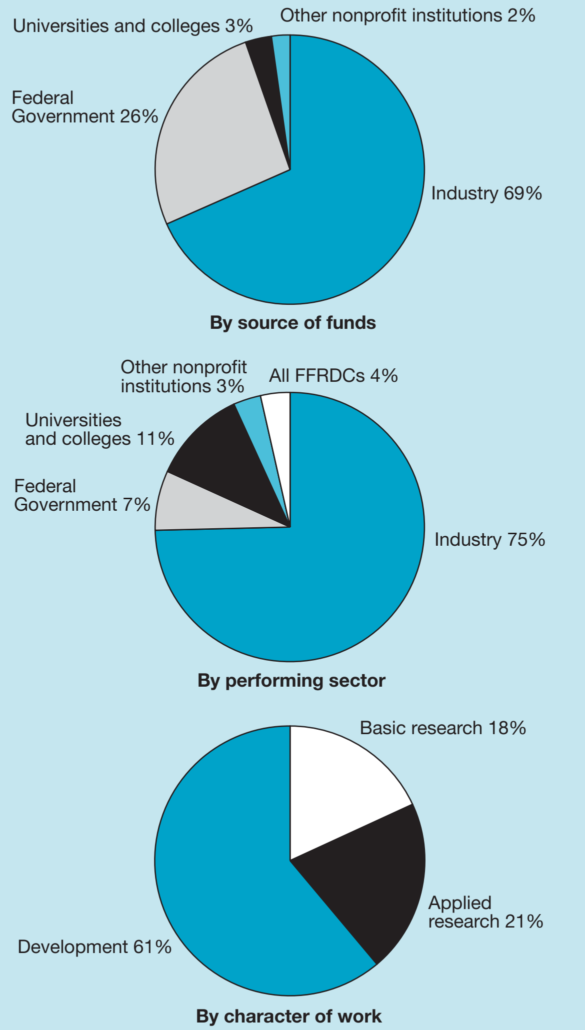
National R&D Growth Trends

Between 1953 and 1969, R&D expenditures grew substantially at a real annual rate of 8.2 percent. However, starting in 1969 and for nearly a decade thereafter, R&D growth failed to keep up with either inflation or general increases in economic output. In fact, between 1969 and 1975, real R&D expenditures declined by 0.9 percent per year, as both business and government tended to deemphasize research programs (See figure 4-1.) Federal funding, in particular, fell considerably during this period—down 2.9 percent in real terms, which was felt in both defense- and nondefense-related programs.

The situation turned around in the mid-1970s. Following an economic recovery from the 1974 oil embargo and the 1975 recession, R&D expenditures increased in real terms by approximately 74.8 percent from 1975 to 1985 (5.7 percent per year) compared with a 40.0 percent rise in real GDP over the same period. During the first half of this period (1975–80), there was considerable growth in Federal R&D funding for nondefense activities. Although defense-related R&D expenditures rose as well, much of the Federal R&D gain was attributable to energy-related R&D (particularly nuclear energy development) and to greater support for health-related R&D. Non-Federal R&D increases were concentrated in industry and resulted largely from greater emphasis on energy conservation and improved use of fossil fuels. Consequently, energy concerns fostered increases in R&D funding by both

[2]In some of the statistics provided in this chapter, FFRDCs are included as part of the sector that administers them. In particular, statistics on the industrial sector often include industry-administered FFRDCs as part of that sector because some of the statistics from the NSF Industry R&D Survey cannot be separated with regard to the FFRDC component. However, whenever a sector is mentioned in this chapter, the wording used will specify whether or not FFRDCs are included. FFRDCs are organizations exclusively or substantially financed by the Federal Government to meet particular requirements or to provide major facilities for research and associated training purposes. Each center is administered by an industrial firm, an individual university, a university consortia, or a nonprofit organization.

Figure 4-2.
Shares of national R&D expenditures: 2000



FFRDCs = Federally Funded Research and Development Centers

NOTE: Data labels rounded to nearest whole number. National R&D expenditures are an estimated $265 billion in 2000.

See appendix tables 4-3, 4-5, 4-7, 4-11, and 4-15.

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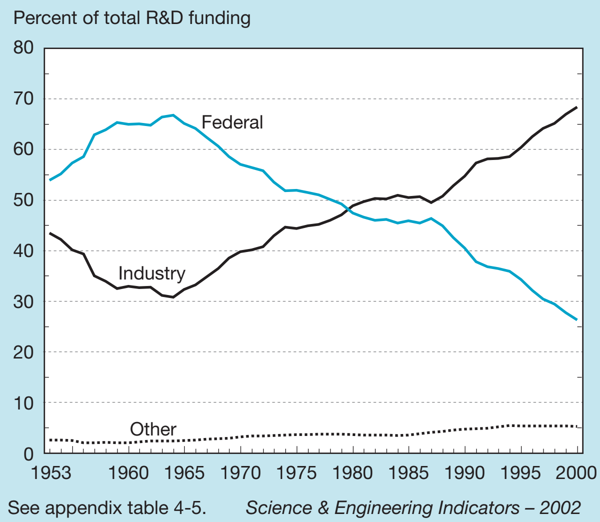
Figure 4-3.
Shares of national R&D expenditures, by source of funds: 1953–2000



See appendix table 4-5. *Science & Engineering Indicators – 2002*

Federal and non-Federal sources. Support for energy R&D rose more than 150 percent in real terms between 1974 and 1979 and accounted for approximately one-half of the national increase in real R&D spending.

Overall, the 1975–80 R&D recovery witnessed an average growth rate of 4.5 percent per year. That annual rate remained between 4 and 5 percent through 1982, although the early 1980s saw a heavy shift toward defense-related activities. As a result of these increases in defense R&D, growth in real R&D expenditures accelerated to an average annual rate of 8.5 percent over 1982–85. Such rapid growth had not been seen since the Sputnik era of the early 1960s.

On average, R&D spending increased 7.0 percent per year in real terms in the first half of the 1980s, then again changed abruptly. In the nine years from 1985 to 1994, average annual R&D growth after inflation slowed to 1.4 percent, vis-à-vis a 2.8 percent annual real growth in GDP. Reductions in both Federal and non-Federal funding of R&D, as a proportion of GDP, had contributed to this slowing. However, it is primarily the decline in real Federal R&D funding that contributed to the slow growth of R&D in the early 1990s.[3]

This downward trend was reversed again in 1994, caused by substantial increases in industrial R&D, most notably in the computer and other information technology sectors.[4] As already indicated, R&D in the United States grew in real terms by 5.8 percent per year between 1994 and 2000, despite little real growth (0.5 percent per year) in Federal R&D support. During the same period, industrial support for R&D grew at a real annual rate of 8.6 percent. Much of this increase might be explained by the favorable economic conditions that generally existed during this period.

[3]These findings are based on performer-reported R&D levels. In recent years, increasing differences have been detected in data on federally financed R&D as reported by Federal funding agencies, on the one hand, and by performers of the work (most notably, industrial firms and universities), on the other hand. This divergence in R&D totals is discussed later in this chapter; see sidebar, "Tracking R&D: Gap Between Performer- and Source-Reported Expenditures."

[4]For a detailed discussion of this upturn, see Jankowski (1998).

Text table 4-1.
U.S. R&D expenditures, by performing sector, source of funds, and character of work: 2000
(Millions of dollars)

Performers	Total	Source of funds: Industry	Federal Government	U&Cs	Other nonprofit institutions	Percent distribution, by performer
Total R&D	264,622	181,040	69,627	8,166	5,789	100.0
Industry	197,280	177,645	19,635	NA	NA	74.6
Industry-administered FFRDCs	2,575	NA	2,575	NA	NA	1.0
Federal Government	19,143	NA	19,143	NA	NA	7.2
U&Cs	30,154	2,310	17,475	8,166	2,203	11.4
U&C-administered FFRDCs	5,801	NA	5,801	NA	NA	2.2
Other nonprofit institutions	8,750	1,085	4,079	NA	3,586	3.3
Nonprofit-administered FFRDCs	918	NA	918	NA	NA	0.3
Distribution by sources (%)	100.0	68.4	26.3	3.1	2.2	NA
Basic research, total	47,903	16,223	23,310	5,023	3,346	100.0
Industry	15,378	14,199	1,179	NA	NA	32.1
Industry-administered FFRDCs	704	NA	704	NA	NA	1.5
Federal Government	3,525	NA	3,525	NA	NA	7.4
U&Cs	20,656	1,421	12,857	5,023	1,355	43.1
U&C-administered FFRDCs	2,809	NA	2,809	NA	NA	5.9
Other nonprofit institutions	4,492	602	1,898	NA	1,991	9.4
Nonprofit-administered FFRDCs	339	NA	339	NA	NA	0.7
Distribution by sources (%)	100.0	33.9	48.7	10.5	7.0	NA
Applied research, total	55,041	36,400	14,460	2,577	1,604	100.0
Industry	37,648	35,396	2,252	NA	NA	68.4
Industry-administered FFRDCs	285	NA	285	NA	NA	0.5
Federal Government	5,826	NA	5,826	NA	NA	10.6
U&Cs	7,260	729	3,259	2,577	695	13.2
U&C-administered FFRDCs	1,401	NA	1,401	NA	NA	2.5
Other nonprofit institutions	2,504	275	1,320	NA	909	4.5
Nonprofit-administered FFRDCs	117	NA	117	NA	NA	0.2
Distribution by sources (%)	100.0	66.1	26.3	4.7	2.9	NA
Development, total	161,679	128,417	31,857	566	839	100.0
Industry	144,254	128,050	16,205	NA	NA	89.2
Industry-administered FFRDCs	1,586	NA	1,586	NA	NA	1.0
Federal Government	9,792	NA	9,792	NA	NA	6.1
U&Cs	2,238	160	1,360	566	153	1.4
U&C-administered FFRDCs	1,592	NA	1,592	NA	NA	1.0
Other nonprofit institutions	1,754	208	860	NA	686	1.1
Nonprofit-administered FFRDCs	463	NA	463	NA	NA	0.3
Percent distribution by sources (%)	100.0	79.4	19.7	0.3	0.5	NA

FFRDCs = Federally Funded Research and Development Centers; U&Cs = universities and colleges; NA = not applicable

NOTES: State and local government support to industry is included in industry support for industry performance. State and local government support to U&Cs ($2,197 million in total R&D) is included in U&C support for U&C performance.

SOURCE: National Science Foundation, Division of Science Resources Studies (NSF/SRS), *National Patterns of R&D Resources: 2000 Data Update,* NSF 01-309 (Arlington, VA, March 2001). Available at <http://www.nsf.gov/sbe/srs/nsf01309/start.htm>.

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Trends in Federal R&D Support by National Objective, Federal Agency, and Performer Sector

Federal Support as a Share of the Nation's R&D Efforts

In recent years, the Federal Government has contributed smaller shares of the nation's R&D funding. The Federal Government had once been the main provider of the nation's R&D funds, accounting for 53.9 percent in 1953 and as much as 66.8 percent in 1964. Its share of R&D funding first fell below 50 percent in 1979 and remained between 44 and 47 percent from 1980 to 1988. Since then, its share has fallen steadily to 26.3 percent in 2000, the lowest ever recorded in the history of the NSF's R&D data series. This decline in the Federal Government share, however, should not be misinterpreted as a decline in the actual amount funded. Federal support in 2000 ($69.6 billion), for example, actually reflects a 0.8 percent increase in real terms over its 1999 level. Because industrial funding increased much faster (see

Definitions of Research and Development

The National Science Foundation (NSF) uses the following definitions in its research and development (R&D) surveys. They have been in place for several decades and generally are consistent with international definitions.

R&D. According to international guidelines for conducting R&D surveys, research and development, also called research and experimental development, comprises creative work that is undertaken on a systematic basis. R&D is performed for the purpose of "increasing the stock of knowledge, including knowledge about humanity, culture, and society," and using "this stock of knowledge to devise new applications" (Organisation for Economic Co-operation and Development (OECD) 1994).

Basic research. The objective of basic research is to gain more comprehensive knowledge or understanding of the subject under study without specific applications in mind. In industry, basic research is defined as research that advances scientific knowledge but does not have specific immediate commercial objectives, although it may be in fields of present or potential commercial interest.

Applied research. Applied research is aimed at gaining the knowledge or understanding to meet a specific, recognized need. In industry, applied research includes investigations oriented to discovering new scientific knowledge that has specific commercial objectives with respect to products, processes, or services.

Development. Development is the systematic use of the knowledge or understanding gained from research directed toward the production of useful materials, devices, systems, or methods, including the design and development of prototypes and processes.

R&D plant. R&D plant includes the acquisition of, construction of, major repairs to, or alterations in structures, works, equipment, facilities, or land for use in R&D activities.

Budget authority. Budget authority is the authority provided by Federal law to incur financial obligations that will result in outlays.

Obligations. Federal obligations represent the amounts for orders placed, contracts awarded, services received, and similar transactions during a given period, regardless of when funds were appropriated or payment required.

Outlays. Federal outlays represent the amounts for checks issued and cash payments made during a given period, regardless of when funds were appropriated or obligated.

above), Federal support as a proportion of the total has continued to decline.

Federal R&D funding, in absolute terms, expanded between 1980 and 2000, from $30.0 to $69.6 billion, which, after inflation, amounted to a small, real growth rate of 1.1 percent per year. This rate, however, was not uniform across the period. From 1980 to 1985, Federal R&D funding grew on average by 6.3 percent in real terms annually. Nearly all of the rise in Federal R&D funding during the early 1980s was due to large increases in defense spending.

Federal support slowed considerably beginning in 1986, reflecting the budgetary constraints imposed on all government programs, including those mandated by the Balanced Budget and Emergency Deficit Control Act of 1985 (also known as the Gramm-Rudman-Hollings Act) and subsequent legislation (notably the Budget Enforcement Act of 1990, which legislated that new spending increases be offset with specific spending cuts). Between 1988 and 1994, Federal R&D support per year declined in real terms from $75.0 billion to $63.3 billion in constant 1996 dollars, but by 2000 had increased slightly to $65.1 billion. From 1996 to 2000, however, the direction of Federal R&D had shifted; for example, Federal support to academia, as a percentage of total Federal support, had risen from 22.2 to 25.1 percent.

Federal Support by National Objective

Defense- and Space-Related R&D. Defense-related R&D, as a proportion of the nation's total R&D, has shifted substantially. From 1953 to 1959, it rose from 48.0 to 54.3 percent; it then declined to a relative low of 24.3 percent in 1980. From 1980 to 1987, it climbed to 31.8 percent. It has fallen substantially since then, reaching a low of 13.6 percent in 2000. (See figure 4-4.)[5]

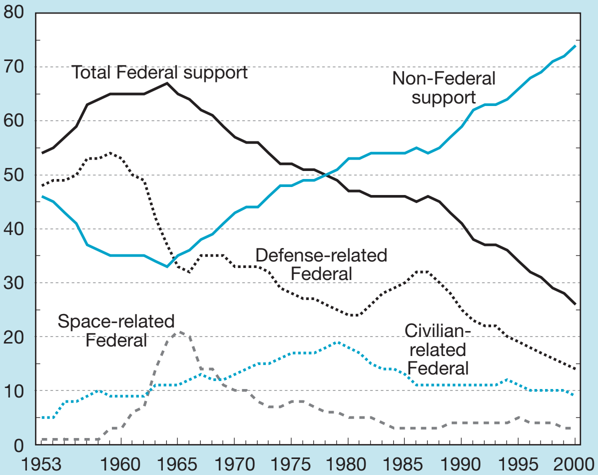
Space-related R&D funding, as a percentage of total R&D funding, reached a peak of 20.9 percent in 1965, during the height of the nation's efforts to exceed the Soviet Union in space travel. It then declined to a low of 3.0 percent in 1986. By 1995, it climbed back up to 4.5 percent, before, once again, slipping to 3.3 percent in 2000. Federal support for civilian-related (that is, nondefense-nonspace) R&D programs, as a percentage of total U.S. R&D, has been declining steadily since 1994, when it was 11.6 percent. It was 9.4 percent in 2000, the lowest since 1962 (when it had been 9.1 percent).

In 1980, the Federal budget authority for defense-related R&D was roughly equal to that for nondefense R&D.[6] (See insert in figure 4-5.) As a result of modifications to U.S. security measures in an evolving international arena, a defense-related R&D expansion occurred in the early and mid-1980s. For example, defense activities of the Department of Defense (DOD) and the Department of Energy (DOE) accounted for approximately one-half of the total Federal R&D budget au-

[5]These shares by national objective represent a distribution of performer-reported R&D data. They are distinct from the budget authority shares reported below that are based on the various functional categories constituting the Federal budget.

[6]R&D budget authority data represent a distribution of Federal source-reported data. See footnote 5.

Figure 4-4.
Trends in Federal and non-Federal R&D expenditures as percentage of total R&D: 1953–2000



See appendix table 4-19. *Science & Engineering Indicators – 2002*

thority in 1980. By 1986, such defense-related activities peaked at 69 percent of the Federal R&D budget authority. (See figure 4-5.) This defense-related R&D expansion was followed by a period of defense-related R&D reductions in the late 1980s and the 1990s. Nondefense R&D, on the other hand, has been increasing steadily since 1983. For fiscal year (FY) 2001, the preliminary budget authority for defense R&D and for nondefense R&D are about equal ($41.4 and $41.3 billion, respectively) and are 42.2 and 43.3 percent higher in real terms than their respective 1980 levels.

Of all the money authorized to be spent by the Federal Government on defense activities in 2001, according to the Federal budget authority, R&D (most of which is development) accounts for 14 percent. In contrast, R&D accounts for about 3 percent of the Federal nondefense budget authority, although many nondefense functions have much higher proportions. (See text table 4-2.) The budget allocation for defense programs declined by an average real annual rate of 1.7 percent from FY 1986 to FY 2001.

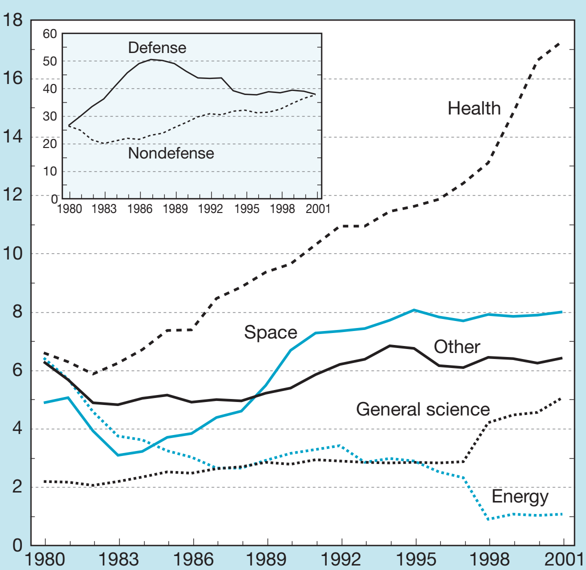
Civilian-Related R&D. Since 1986, the Federal budget authority for civilian-related R&D grew faster than that for defense-related R&D. In particular, the budget allocation for health- and space-related R&D increased substantially between FY 1986 and FY 2001, with average real annual growth rates of 5.8 and 5.0 percent, respectively. (As indicated in figure 4-5, most of this growth in the budget authority for space-related R&D occurred between FY 1986 and FY 1991.)

With regard to nondefense objectives (or "budget functions"), R&D accounts for 71.6 percent of funds for general science of which 80.7 percent is devoted to basic research. (See text table 4-2.) R&D accounts for only 7.4 percent of funds for natural resources and the environment, nearly all of which (91.7 percent) is devoted to applied R&D. Among funds for health, R&D represents 11.1 percent, most of which (55.1 percent) is devoted to basic research and nearly all of which is directed toward National Institutes of Health (NIH) programs.

At first glance, the R&D budget authority for energy appears to have declined rapidly in recent years, notably, from $2.3 billion in FY 1997 to only $0.9 billion in FY 1998 in constant 1996 dollars (as shown in figure 4-5). However, this effect was not an actual decline in economic resources devoted to energy R&D but merely the result of reclassification. Beginning in FY 1998, several DOE programs were reclassified from "energy" to "general science," so that the drop in energy R&D was equally offset by a rise in general science from $2.9 to $4.2 billion in constant 1996 dollars. (See also sidebar, "The Federal Science and Technology Budget and Related Concepts.")

Understanding the Growth in Federal Health-Related R&D. As illustrated in figure 4-5, the budget allocation for health-related R&D increased dramatically between FY 1982 and FY 2001, with an average real annual growth rate of 5.8 percent. As a result, health-related R&D rose from representing roughly one-quarter (27.5 percent) of the Federal, nondefense R&D budget allocation in FY 1982 to nearly one-half (45.6 percent) by FY 2001. Many individuals in the science community have expressed the concern that health-related R&D has received the lion's share of increases in Federal support for R&D, whereas the other broad areas (e.g., space, general science, energy, and the environment) have experienced much lower growth, or even declines, in Federal support.

Figure 4-5.
Federal R&D funding, by budget function: FYs 1980–2001



NOTES: "Other" includes all nondefense functions not separately graphed, such as agriculture and transportation. The 1998 increase in general science and decrease in energy resulted from a reclassification.

See appendix table 4-26. *Science & Engineering Indicators – 2002*

Text table 4-2.
Budget authority for R&D by function and character of work: proposed levels for FY 2001
(Millions of dollars)

Budget function	Basic research	Applied research and development	R&D total	R&D as percentage of total budget
Total	20,259	62,472	82,730	7.7
National defense	1,262	40,152	41,414	13.6
Health	10,399	8,459	18,858	11.1
Space research and technology	1,761	6,971	8,732	66.7
General science	5,272	257	5,529	71.6
Natural resources and environment	162	1,771	1,932	7.4
Transportation	202	1,462	1,665	2.8
Agriculture	702	748	1,450	6.4
Energy	46	1,138	1,184	NA
All other	453	1,515	1,967	NA

NA = not applicable

NOTE: Total budget authority used in the percentage calculation (last column) includes only those functions in which R&D is conducted.

SOURCE: National Science Foundation, Division of Science Resources Studies (NSF/SRS), *Federal R&D Funding by Budget Function: Fiscal Years 1999–2001*, NSF 01-316 (Arlington, VA, 2001).

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Although there is no consensus as to why health-related research has continued to receive increased Federal support, the current framework under which the Federal Government provides support for health and medical research can be traced back to important position statements made in the aftermath of World War II. These positions were expressed in two important reports: a 1947 report by J. Steelman entitled "Science and Public Policy" and a 1945 report by V. Bush entitled "Science—The Endless Frontier: A Report to the President on a Program for Postwar Scientific Research." These reports promoted support for other fields of science, but their specific focus on the topic of health research has supported the argument for growth in its Federal support since. In the early 1970s, medical research was promoted by the nation's war on cancer, and in the 1980s it was promoted by the nation's (and the world's) concern over the acquired immune deficiency syndrome (AIDS) epidemic (Jankowski 2001a). Growth in health-related R&D in the 1990s has supported research on cancer and AIDS as well, but a great deal of the new funding has been directed toward other disease areas. Part of the reason for the observed growth of health-related R&D stems from opportunities afforded by biotechnology research advances, but perhaps part of the growth comes also from the influence of disease-specific lobbying groups.

R&D by Federal Agency

According to preliminary data provided by Federal agencies, DOD will obligate the most funds among Federal agencies for R&D support in FY 2001, $36.4 billion (44.6 percent) of all Federal R&D obligations. (See text table 4-3.) The bulk of these funds ($32 billion) will be for development as compared with basic or applied research. The agency obligating the second largest amount in R&D support is the Department of Health and Human Services (HHS) with $19.2 billion, most of which ($10.4 billion) will be for basic research, followed by the National Aeronautics and Space Administration (NASA) with $9.6 billion (most of which will be for development), DOE with $6.8 billion (nearly equally divided among basic research, applied research, and development), and NSF with $3.2 billion (almost all of which will be for basic research). Together, these five agencies account for 92.2 percent of all estimated Federal support for R&D in 2001: 93.1 percent of Federal support for basic research, 78.7 percent of Federal support for applied research, and 97.7 percent of Federal support for development.

The majority of HHS's R&D support (57 percent) is directed toward academia. By preliminary estimates, HHS accounted for 61.9 percent of all Federal R&D obligations to universities and colleges, excluding university-administered FFRDCs in FY 2001. (See text table 4-4.) A total of 23.6 percent is spent internally, mostly in NIH laboratories. HHS also accounts for 71.6 percent of all Federal R&D obligations for nonprofit organizations in FY 2001. Approximately 6 percent of HHS R&D obligations are slated for industrial firms.

NSF and DOD are the other leading supporters of R&D conducted in academic facilities. (See text table 4-4.) Universities and colleges account for 82.8 percent of NSF's R&D budget. The bulk of the remaining NSF budget is divided between university-administered FFRDCs (6.1 percent), other nonprofit organizations (5.8 percent), and industry (3.6 percent). In FY 2001, DOD provides only 4.2 percent of its R&D support to universities and colleges, in contrast to 69.5 percent to industry and 23.6 percent to Federal intramural activities. By comparison, DOE provides 10.4 percent of its support to universities, 16.8 percent to industry, 12.8 percent to Fed-

The Federal Science and Technology Budget and Related Concepts

In recent years, alternative concepts have been used to isolate and describe fractions of Federal support that could be associated with scientific achievement and technological progress. In a 1995 report (National Academy of Sciences 1995), members of a National Academy of Sciences (NAS) committee proposed an alternative method of measuring the Federal Government's science and technology (S&T) investment. According to the committee members, this approach, titled the Federal Science and Technology (FS&T) budget, might provide a better way to track and evaluate trends in public investment in R&D. The FS&T concept differed from Federal funds for research in that it did not include major systems development supported by the Department of Defense and the Department of Energy, and it contained not only research but also some development and some R&D plant.

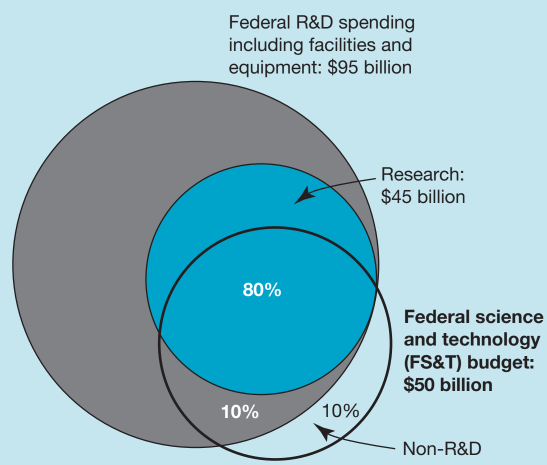
In the fiscal year (FY) 1999 budget, an alternative concept, the "Research Fund for America" (RFA), was introduced, which reflected an interest in addressing the FS&T concept previously proposed by NAS. Unlike the FS&T budget, however, which was constructed from components of the R&D budget, the RFA was constructed of easily tracked programs and included some non-R&D programs, such as National Science Foundation (NSF) education programs and staff salaries at the National Institutes of Health and NSF. The RFA consisted of only civilian (nondefense) R&D; it captured 94 percent of civilian basic research, 72 percent of civilian applied research, and 51 percent of civilian development. The FY 2000 budget referred to the concept "21st Century Research Fund," which was a slight modification of the RFA.

In the 2002 Budget of the United States, the 21st Century Research Fund is no longer mentioned, and the concept of the FS&T budget is readdressed. The new FS&T budget is approximately one-half of total Federal spending on R&D because it excludes funding for defense development, testing, and evaluation. It includes nearly all of the budgeted Federal support for basic research in FY 2002, more than 80 percent of federally supported applied research, and approximately 50 percent of federally supported nondefense development (U.S. Office of Management and Budget (OMB) 2001c).

As shown in figure 4-6, Federal R&D in the 2002 budget proposal, which includes expenditures on facilities and equipment, would reach a level of $95 billion. Of this amount, $45 billion would be devoted to basic and applied research alone. The FS&T budget would reach $50 billion and would include most of the research budget. However, differences in the definition of research and FS&T imply that not all research would be included in FS&T and vice versa. Moreover, a small proportion (10 percent) of FS&T funds would fall outside the category of Federal R&D spending.

Hence, the current FS&T budget developed by OMB largely includes the same programs that constitute the ongoing NAS FS&T categorization effort, a development that should ease analyses of these budgetary issues.

Figure 4-6.
Comparison of funding concepts in the FY 2002 budget proposal



NOTE: Percentages represent shares of the FS&T budget.

SOURCE: U.S. Office of Management and Budget, *Budget of United States Government: FY 2002* (Washington, DC, 2001).

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eral intramural activities, and 35.3 percent to FFRDCs administered by universities and colleges.

Of all Federal obligations of R&D funds to FFRDCs in FY 2001, DOE accounted for 61.3 percent, NASA for another 19.8 percent, and DOD for 11.5 percent. More than one-half (59.1 percent) of DOE's R&D support is directed toward FFRDCs.

Unlike the other Federal agencies just mentioned, the U.S. Department of Agriculture (USDA), Department of Commerce (DOC), and Department of the Interior (DOI) spend most of their R&D obligations internally. Most of the R&D supported by these agencies is mission-oriented and conducted in their own laboratories, which are run, respectively, by the Agricultural Research Service, the National Institute for Standards and Technology (NIST), and the U.S. Geological Survey.

In contrast to total R&D obligations, which are devoted primarily to extramural R&D activities, only three agencies had intramural R&D expenditures that exceeded $1 billion in 2001 (which includes the costs associated with planning and administering extramural R&D programs): DOD, HHS (which includes NIH), and NASA. Together, these three agencies account for 76.2 percent of Federal intramural R&D.

Text table 4-3.
Federal R&D obligations, total and intramural by U.S. agency: FY 2001

Agency	Total R&D obligations (millions of dollars)	Total R&D obligations as share of Federal total (percent)	Intramural R&D[a] (millions of dollars)	Percentage of intramural R&D obligations	Percent change in real intramural R&D from previous year[b]
Federal Government total	81,526.2	100.0	19,352.4	23.7	–0.6
Department of Defense	36,396.6	44.6	8,578.8	23.6	–7.5
Department of Health and Human Services	19,234.6	23.6	3,678.1	19.1	3.7
National Aeronautics and Space Administration	9,602.4	11.8	2,496.9	26.0	5.5
Department of Energy	6,793.5	8.3	871.0	12.8	10.4
National Science Foundation	3,179.9	3.9	27.1	0.9	17.4
Department of Agriculture	1,779.3	2.2	1,250.5	70.3	8.0
Department of Commerce	1,127.0	1.4	775.8	68.8	0.9
Department of Transportation	866.1	1.1	289.3	33.4	36.4
Department of the Interior	619.4	0.8	545.9	88.1	8.0
Environmental Protection Agency	530.1	0.7	125.1	23.6	–3.3
Department of Veterans Affairs	367.0	0.5	367.0	100.0	–2.0
Department of Education	307.3	0.4	38.9	12.7	79.7
Agency for International Development	216.9	0.3	26.0	12.0	2.7
Smithsonian Institution	103.0	0.1	103.0	100.0	4.0
Department of Justice	102.8	0.1	44.7	43.5	10.6
Department of the Treasury	67.8	0.1	52.7	77.7	16.8
Department of Labor	66.0	0.1	22.3	33.8	9.8
Department of Housing and Urban Development	62.7	0.1	35.9	57.3	6.2
Nuclear Regulatory Commission	53.0	0.1	14.9	28.1	–35.7
Social Security Administration	41.6	0.1	1.2	2.9	–53.0
Federal Communications Commission	3.5	0.0	3.5	100.0	–12.1
Library of Congress	2.1	0.0	1.6	76.2	11.9
Department of State	1.5	0.0	0.5	33.3	–2.1
Federal Trade Commission	1.4	0.0	1.4	100.0	14.3
Appalachian Regional Commission	0.8	0.0	0.0	0.0	0.0
National Archives and Records Administration	0.1	0.0	0.1	0.0	0.0

[a]Intramural activities include actual intramural R&D performance and the costs associated with the planning and administration of both intramural and extramural programs by Federal personnel.

[b]Based on fiscal year GDP implicit price deflators. (See appendix table 4-1.)

SOURCE: National Science Foundation, Division of Science Resources Studies (NSF/SRS), *Federal Funds for Research and Development: Fiscal Years 1999, 2000, and 2001,* NSF 01-328 (Arlington, VA, June 2001).

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Federal Support to Academia

The Federal Government has long provided the largest share of R&D funds used by universities and colleges. In the early 1980s, Federal funds accounted for roughly two-thirds of the academic total. By 1991, however, that share had dropped to 58.6 percent, and it has since remained between 58 and 60 percent. Although this share of funding has not changed much in recent years, the actual amount of funding, in real terms, has grown on average by 5.1 percent per year between 1985 and 1994 and by 3.2 percent between 1994 and 2000. For more information on academic R&D, see chapter 5.[7]

Federal Funding to Industry

The greatest fluctuation in Federal support has been in Federal funds to industry (excluding industry-administered FFRDCs), which rose from a low of $7.4 billion in constant 1996 dollars in 1953 (when the NSF time series began) to a relative maximum of $32.6 billion in 1966.[8] (See figure 4-7.) It then declined to a relative minimum of $19.7 billion (constant 1996 dollars) in 1975; rose sharply to $37.1 billion by 1987; and fell sharply again to $21.1 billion by 1994. From 1994 to 2000, Federal support to industry has been relatively unchanged, ranging from $18.4 to $21.1 billion in constant 1996 dollars. Most recently, between 1999 and 2000, there was a 4.6 percent decline, in real terms, in Federal funds for industrial R&D activities. Overall, the Federal share of industry's performance has been steadily declining since its peak of 56.7 percent reached in 1959. Much of that decline can be attributed to declines in Federal funding to industry for defense-related R&D activities.

[7]Related topics in this chapter include "Industry-University Collaboration" in the section "Research Alliances: Trends in Industry, Government, and University Collaboration" and "Higher Education Sector" under "International Comparisons of National R&D Trends".

[8]The 1953 value is actually an overestimate because the 1953 and 1954 figures for Federal support to industry include support to industry-administered FFRDCs; the figures for subsequent years do not.

Text table 4-4.
Estimated Federal R&D obligations, by performing sector and agency funding source: FY 2001

Character of work and performer	Total obligations ($ millions)	Primary funding source		Secondary funding source	
		Agency	Percent	Agency	Percent
Total R&D	81,526	DOD	45	HHS	24
Federal intramural laboratories	19,352	DOD	44	HHS	19
Industrial firms	33,026	DOD	77	NASA	14
Industry-administered FFRDCs	1,386	DOE	77	HHS	13
Universities and colleges	17,724	HHS	62	NSF	15
Universities and college FFRDCs	4,189	DOE	57	NASA	31
Other nonprofit organizations	4,176	HHS	72	NASA	9
Nonprofit-administered FFRDCs	978	DOE	56	DOD	40
Basic research, total	20,274	HHS	51	NSF	15
Federal intramural laboratories	3,650	HHS	46	USDA	17
Industrial firms	1,193	HHS	37	NASA	33
Industry-administered FFRDCs	325	DOE	67	HHS	33
Universities and colleges	10,906	HHS	59	NSF	23
Universities and college FFRDCs	1,747	DOE	65	NASA	22
Other nonprofit organizations	1,980	HHS	83	NSF	9
Nonprofit-administered FFRDCs	340	DOE	91	DOD	5
Applied research, total	18,414	HHS	33	DOD	17
Federal intramural laboratories	6,142	HHS	25	DOD	18
Industrial firms	3,925	DOD	37	NASA	36
Industry-administered FFRDCs	586	DOE	83	HHS	10
Universities and colleges	4,790	HHS	66	DOD	10
Universities and college FFRDCs	1,201	DOE	68	NASA	24
Other nonprofit organizations	1,360	HHS	68	NASA	8
Nonprofit-administered FFRDCs	130	DOE	72	DOD	10
Development, total	42,838	DOD	75	NASA	11
Federal intramural laboratories	9,560	DOD	74	NASA	13
Industrial firms	27,908	DOD	85	NASA	10
Industry-administered FFRDCs	474	DOE	77	DOD	18
Universities and colleges	2,027	HHS	68	DOD	21
Universities and college FFRDCs	1,241	NASA	49	DOE	36
Other nonprofit organizations	835	HHS	49	NASA	23
Nonprofit-administered FFRDCs	508	DOD	70	DOE	28

FFRDCs = Federally Funded Research and Development Centers; DOD = Department of Defense; HHS = Department of Health and Human Services; NASA = National Aeronautics and Space Administration; DOE = Department of Energy; NSF = National Science Foundation, USDA = Department of Agriculture.

SOURCE: National Science Foundation, Division of Science Resources Studies (NSF/SRS), *Federal Funds for Research and Development: Fiscal Years 1999, 2000, and 2001,* NSF 01-328 (Arlington, VA, June 2001).

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Federal R&D financing for specific industrial sectors (including the industry FFRDCs that belong to those sectors) has varied markedly across time and across different industries. The Federal Government provided $22.5 billion for industry R&D in 1999, the most recent year for which detailed data by industrial category are available. Aerospace companies (or the industrial sector "aircraft and missiles") received 40.5 percent of Federal R&D funds provided to all industries. Consequently, 63.2 percent of the aerospace industry's R&D dollars came from Federal sources; the remaining 36.8 percent came from those companies' own funds. In comparison, the drugs and medicines sector in 1999 financed 100 percent of its R&D from company funds; machinery, 93.4 percent; computer and electronic products, 83.3 percent; transportation equipment other than aircraft and missiles, 95.3 percent; information services, 96.8 percent; and professional, scientific, and technical services, 75.7 percent.[9] See sidebar, "National Science Board Study on Federal Research Resources: A Process for Setting Priorities."

The Federal R&D Tax Credit

In addition to direct R&D funding and government-performed research, the Federal Government provides a research and experimentation (R&E) tax credit aimed at stimulating research investment. In particular, the credit reduces the costs of using internal funds to fund private R&D activities. This tax credit on incremental research expenditures has been in place in the United States since 1981, having been renewed 10 times because of its temporary status. Most recently, the R&E tax credit was reinstated in the Tax Relief Extension Act of 1999 through June 2004.[10] As of this writing, the FY 2002 budget of the Bush administration proposes to make the R&E credit permanent (U.S. OMB 2001a).

[9] The 100 percent company funding for the drugs and medicines sector does not include the benefits this sector receives from R&D financed by NIH.

[10] Public Law 106-170, Title V, December 1999.

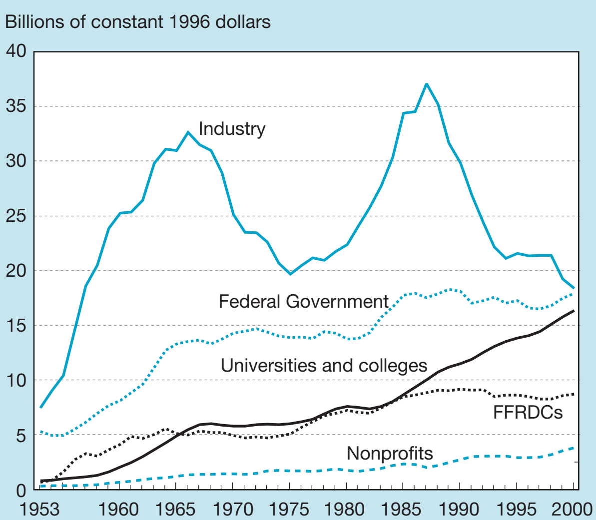
National Science Board Study on Federal Research Resources: A Process for Setting Priorities

The National Science Board (the Board) undertook an intensive two-year study on budget coordination and priority setting for government-funded research. The study included review of the literature on Federal budget coordination and priority setting for research, and invited presentations from and discussions with representatives of the Office of Management and Budget, the Office of Science and Technology Policy, the Federal R&D agencies, congressional staff, high-level science officials from foreign governments, experts on data and methodologies, and spokespersons from industry, the National Academies, research communities, science policy community, and academe. Discussions focused on research priority setting as it is practiced in government organizations, and possibilities for enhancing coordination and priority setting for the Federal research budget. After considering this information, the Board finds that:

- The appropriate focus for advice from the Board is the budget allocation processes for research within the White House and Congress that in the aggregate produce the Federal research portfolio.
- The allocation of funds to national research goals is ultimately a political process that should be informed by the best scientific advice and data available.
- A strengthened process for research allocation decisions is needed. Such allocations are based now primarily on faith in future payoffs justified by past success, but are difficult to defend against alternative claims on the budget that promise concrete, more easily measured results and are supported by large and vocal constituencies.
- The pluralistic framework for Federal research is a positive aspect of the system and increases possibilities for funding high-risk, high-payoff research. An improved process for budget coordination and priority setting should build on strengths of the current system and focus on those weaknesses that can be addressed by improved data and broad-based scientific input representing scientific communities and interests across all sectors.
- There is a need for regular evaluation of Federal investments as a portfolio for success in achieving Federal goals for research to identify areas of weakness in the national infrastructure for science and technology, and to identify a well-defined set of top priorities for major new research investments.
- Additional resources are needed to provide both Congress and the Executive branch with data, analyses, and expert advice to inform their decisions on budget allocations for research.

The full report, with NSB recommendations, can be accessed at: <http://www.nsf.gov/nsb/>.

Figure 4-7.
Federal R&D support, by performing sector: 1953–2000



FFRDCs = Federally Funded Research and Development Centers

See appendix table 4-6. *Science & Engineering Indicators – 2002*

The standard policy justification for a tax stimulus is that results from research, especially long-term research, often are hard to capture privately, as others might benefit directly or indirectly from it. Therefore, businesses might engage in levels of research below those that would benefit a broader constituency, such as a whole industry or the nation. In fact, many developed economies have in place some form of tax credit for research activity.[11]

Structure of the Credit and Tax Data

A regular credit is provided for 20 percent of qualified research above a base amount based on the ratio of research expenses to gross receipts for 1984–88. Younger companies follow different formulas. An alternative R&E credit is available for corporate fiscal years that began after June 30, 1996.[12] Both the regular and the alternative R&E credits include provi-

[11]For R&D tax policies abroad, see "Government Sector" under "International R&D by Performer, Source, and Character of Work" later in this chapter.

[12]The alternative credit is a lower rate that applies to all research expenses exceeding 1 percent of revenues or sales. The rates were raised by the 1999 Tax Relief Act to 2.65–3.75 percent. Companies may select only one of these two credit modes on a permanent basis, unless the Internal Revenue Service authorizes a change. The 1999 Act also extended the research credit to include R&D conducted in Puerto Rico and the U.S. possessions (U.S. OMB 2000).

sions for basic research payments paid to qualified universities or scientific research organizations above a certain base period amount. Qualified research covers “research undertaken to discover information, technological in nature, and useful in the development of a new or improved business component” (U.S. IRS 2000).[13] Because the focus is on domestic research performance, R&D conducted in the United States by foreign firms also is covered, whereas R&D conducted abroad by foreign affiliates of U.S. parent companies is not eligible.

The types of firms that claim the credit and their level of participation are affected by the provisions of the credit, including the definition of covered R&D and the spending base, offsetting credits or caps, and its temporary status. In addition, empirical studies of the effects of the tax credit also have to separate purely accounting effects, such as possible reclassification of activities or timing effects, from real changes in research spending. Thus, to assess precisely whether a particular tax incentive is inducing the kinds of research activities targeted by the credit is difficult at best. Nevertheless, Hall and Van Reenen (2000), based on a review of U.S. studies from the early 1980s to late 1990s, conclude that a dollar in tax credit likely stimulates a dollar of additional R&D. As an empirical generalization, however, this conclusion might not apply fully to certain segments of R&D performers, such as small companies or startup firms.

Total R&E credit claims and number of returns applying for the credit are available from Statistics of Income, Internal Revenue Service (IRS). In 1998 (the latest year for which these data are available), more than 9,800 returns claimed $5.208 billion in R&E credits, up 18.4 percent from 1997 dollar claims (U.S. IRS 2001).[14] The unusual doubling of the credit over 1996–97 followed a 12-month gap in the credit. (See text table 4-5). However, not all R&E claims are allowed because there is a limitation on the reduction of a company’s total tax liability. Most claimants applied for the regular 20 percent credit. In 1998, total basic research credits were $398 million, or 7.6 percent of the total R&E credit, claimed by 551 returns.

Nearly three-fourths of R&E credit claims come from manufacturing corporations in any given year. An analysis by Whang (1998) using 1995 tax data identified pharmaceuticals, motor vehicles, aircraft, electronics, and computers as the industries with the largest claims. The author also reported that firms with at least $250 million in assets accounted for three-fourths of the dollar value of all credit claims for the same tax year. Another study, based on a 1998 survey sponsored by the Small Business Administration (SBA), found that only 71 of 194 (37 percent) small firms that responded to a question on the R&E tax credits reported claiming the credit (Cordes, Hertzfeld, and Vonortas 1999). Furthermore, only 28 of the survey firms claiming the tax credit reported that the credit stimulated additional R&D by an amount equal to or more than the amount of the credit. Of the small firms not claiming the credit, approximately one-half failed to exceed the statutory base for the credit, and about one-fourth considered the tax credit procedures too complicated to allow their participation.[15]

Federal Budget Impact

In the language of the Federal budget, R&E credits fall in the category of tax expenditures—government revenue losses due to preferential provisions. According to the Treasury Department, the largest tax expenditures are those associated with the individual income tax. Tax expenditures from corporate income taxes relate mostly to cost recovery for certain investments, including research activities. The outlay-equivalent measure is one of three accounting methods used to estimate these tax expenditures.[16] This method translates R&E credits in terms comparable to Federal R&D outlays. This allows a comparison of the cost of the tax expenditure with that of a direct Federal outlay (U.S. OMB 2001a).

According to this measure, tax credit claims in 1998 were equivalent to outlays of $3.270 billion, or 4.6 percent of direct Federal R&D outlays in FY 1998 (See figure 4-8.) Although R&E claims data for tax year 2000 are not available, the credit generated an estimated outlay equivalent of $2.510 billion, or 3.4 percent of Federal R&D outlays in FY 2000. In constant 1996 dollars, the average outlay equivalent over 1981–2000 is $2.1 billion.

Text table 4-5.
Research and experimentation tax credit claims

Year	Billions of current dollars	Number of tax returns
1990	1.547	8,699
1991	1.585	9,001
1992	1.515	7,750
1993	1.857	9,933
1994	2.423	9,150
1995	1.422	7,877
1996	2.134	9,709
1997	4.398	10,668
1998	5.208	9,849

SOURCE: U.S. Department of the Treasury, Internal Revenue Service, Statistics of Income, unpublished tabulations (Washington, DC, 2001).

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Historical Trends in Non-Federal Support

R&D financing from non-Federal sources grew by 5.9 percent per year after inflation between 1953 and 1980. Between 1980 and 1985, concurrent with gains in Federal R&D spending, it grew by an even faster rate of 7.6 percent per year in

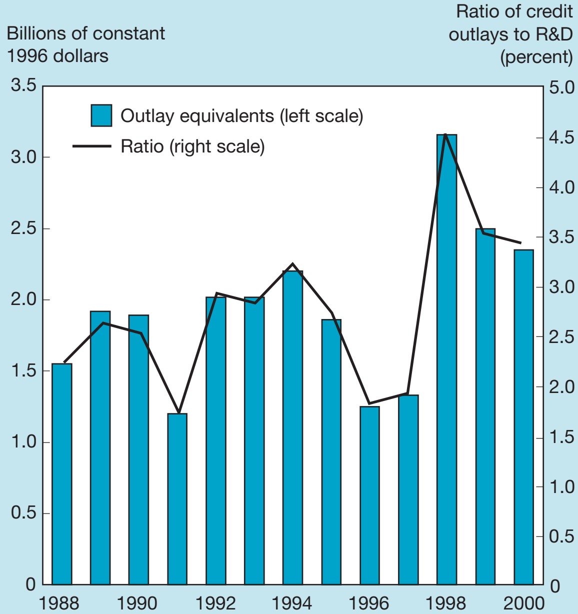
[13]The credit excludes research in the social sciences and humanities.

[14] Data for active corporations, other than forms 1120S, 1120-TEIT, and 1120-RIC.

[15] The study is based on a random sample of 1,053 small firms (fewer than 500 employees), of which 91 percent were privately owned; 198 small firms completed the survey. The average responding firm had a mean age of 23 years, 79 employees, and $5.7 million in annual sales.

[16] The other two measures are revenue loss and present value of tax expenditures. For a comparison of these methods, see U.S. OMB (2001a).

Figure 4-8.
Budgetary impact of Federal research and experimentation tax credit: FYs 1988–2000



NOTE: The ratio of credit outlays to R&D is the outlay equivalent cost of the tax credit divided by total Federal R&D outlays.

See appendix table 4-30. *Science & Engineering Indicators – 2002*

real terms. It then slowed to 4.4 percent between 1985 and 1990 and to 3.3 percent between 1990 and 1995 but rose to 8.2 percent over the 1995–2000 period.

As already discussed, most non-Federal R&D support is provided by industry. Of the 2000 non-Federal support total ($195 billion), 92.8 percent ($181 billion) was company funded. Industry's share of national R&D funding first surpassed that of the Federal Government in 1980, and it has remained higher ever since. From 1980 to 1985, industrial support for R&D, in real dollars, grew at an average annual rate of 7.7 percent. This growth was maintained through both the mild 1980 recession and the more severe 1982 recession. (See figure 4-1.) Key factors behind increases in industrial R&D included a growing concern with international competition, especially in high-technology industries; the increasing technological sophistication of products, processes, and services; and general growth in defense-related industries, such as electronics, aircraft, and missiles.

Between 1985 and 1994, growth in R&D funding from industry was slower, averaging only 3.1 percent per year in real terms. This slower growth in industrial R&D funding was only slightly greater than the real growth of the economy over the same period (in terms of real GDP), which was 2.8 percent. In contrast, from 1994 to 2000, non-Federal R&D support grew in real terms by 8.6 percent per year compared with 4.0 percent for the economy overall.

R&D funding from other non-Federal sectors, namely, academic and other nonprofit institutions and state and local governments, has been more consistent over time. It grew in real terms at average annual rates of 6.4 percent between 1980 and 1985, 8.5 percent between 1985 and 1990, 3.8 percent between 1990 and 1995, and 5.5 percent between 1995 and 2000. The level of $14.0 billion in funding in 2000 was 4.9 percent higher in real terms than its 1999 level of $13.0 billion. Most of these funds had been used for research performed within the academic sector.

R&D Performance in the United States

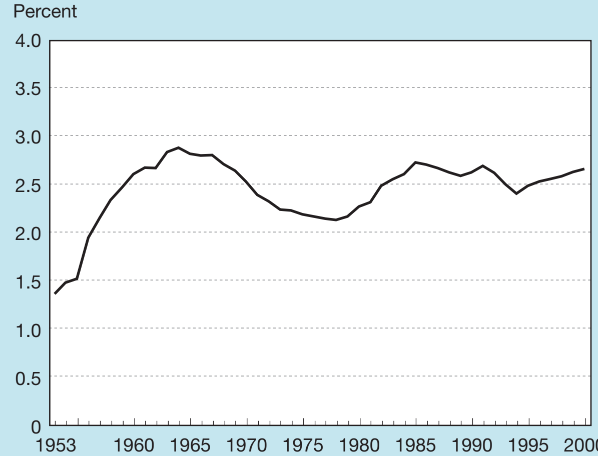
U.S. R&D/GDP Ratio

Growth in R&D expenditures should be examined in the context of the overall growth of the economy, because, as a part of the economy itself, R&D is influenced by many of the same factors. Furthermore, as mentioned earlier, the ratio of R&D expenditures to GDP may be interpreted as a measure of the nation's commitment to R&D relative to other endeavors.

A review of U.S. R&D expenditures as a percentage of GDP over time shows an initial low of 1.36 percent in 1953 (when the NSF data series began), rising to its highest peak of 2.88 percent in 1964, followed by a gradual decline to 2.12 percent in 1978. (See figure 4-9.) From that low in 1978, U.S. R&D expenditures again rose steadily to peak at 2.72 percent in 1985 and did not fall below 2.50 until 1993. In 1994, the rate dropped to 2.40, its lowest point since 1981. Starting in 1994, however, R&D/GDP has been on an upward trend as investments in R&D have outpaced growth of the general economy. As a result, the current ratio of 2.66 for 2000 is the highest the ratio has been since 1985.

The initial drop in the R&D/GDP ratio from its peak in 1964 largely reflects Federal cutbacks in defense and space R&D programs, although gains in energy R&D activities between 1975 and 1979 resulted in a relative stabilization of the ratio between

Figure 4-9.
Historical pattern of R&D as percentage of GDP: 1953–2000



See appendix tables 4-1 and 4-3.

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2.1 and 2.2 percent. Over the entire 1965–78 period, the annual percentage increase in real R&D was less than the annual percentage increase in real GDP. When real R&D spending decreased during that period, real GDP also fell, but at a lower rate.

The rise in R&D/GDP from 1978 to 1985 was due as much to a slowdown in GDP growth as it was to increased spending on R&D activities. For example, the 1980 and 1982 recessions resulted in a slight decline in real GDP, but there was no corresponding reduction in R&D spending. During previous recessions, changes in funding for R&D tended to match or exceed the adverse movements of the broader economic measures.

The share of defense-related R&D dropped from 31 percent in 1985 to 23 percent in 1991. Commensurate with this change was the sharp fall in the share of federally funded R&D, from 46 percent in 1985 to 37.8 percent in 1991. (See figure 4-4.) This decline in Federal funding was counterbalanced by increased non-Federal funding, as described earlier in the discussion of industrial trends. Indeed, since the late 1980s, practically all of the rise in the R&D/GDP ratio has resulted from gains in industrial R&D spending.

From 1991 to 1994, the R&D/GDP ratio declined from 2.69 to 2.40. Since then, however, it has risen steadily. Between 1994 and 2000, the R&D supported by industry grew in real terms by 8.6 percent annually, whereas real GDP grew by 4.0 percent, largely explaining the rise in the R&D/GDP ratio to 2.66 in 2000. From 1992 to 2000, the ratio of research alone to GDP has remained at 1.0 percent, while the ratio of development to GDP has varied between 1.5 and 1.6 percent. Within the industrial sector, however, development plays a greater role. In 1999, for example, the ratio of research performance to net sales in industry was 0.8 percent, while the ratio of development to net sales was 2.0 percent.

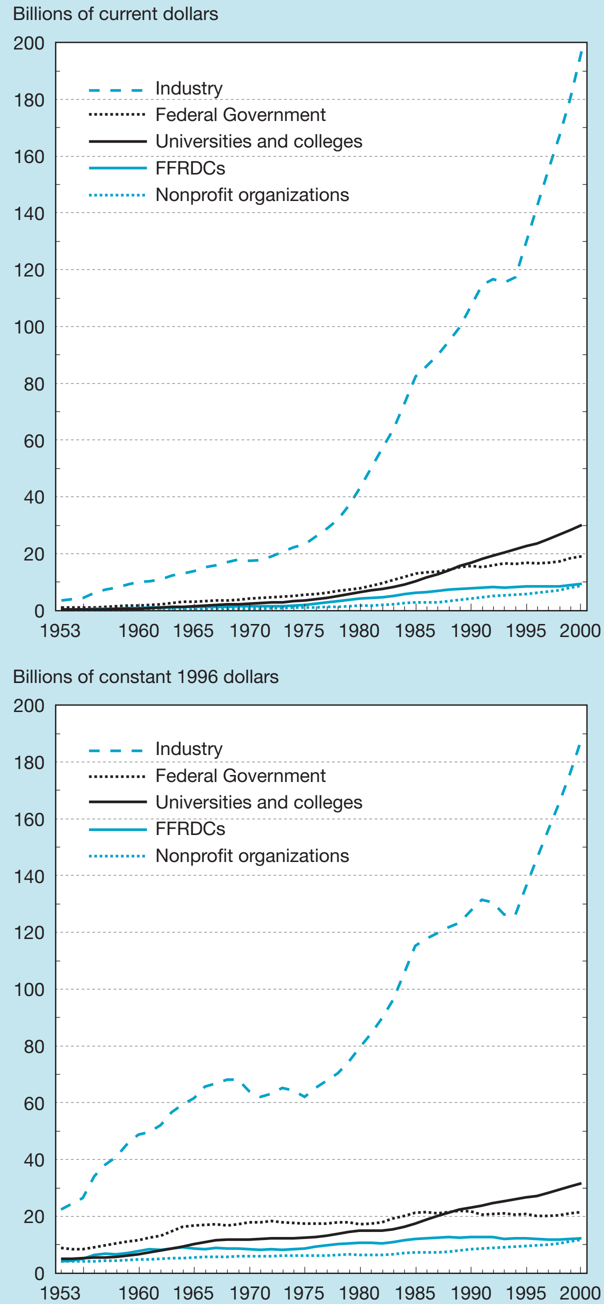
Rates of Growth Among Sectors

The sectoral shares of U.S. R&D performance have shifted significantly since the early 1980s. (See figure 4-10 for levels of expenditure.) In 1980, industry (including industry-administered FFRDCs) performed 70.3 percent of the nation's R&D; the academic sector (including academically administered FFRDCs) accounted for 13.9 percent; the Federal Government accounted for 12.4 percent; and the nonprofit sector (including nonprofit-administered FFRDCs) accounted for 3.3 percent. Industry's defense-related R&D efforts accelerated in the early 1980s, and its share of performance total rose to 73.4 percent in 1985.

From 1985 to 1994, R&D performance grew by only 1.4 percent per year in real terms for all sectors combined. This growth was not evenly balanced across performing sectors, however. R&D performance at universities and colleges (including their FFRDCs) grew by 4.4 percent per year in real terms compared with only 1.0 percent growth for industry (including their FFRDCs), a decline of 0.5 percent per year for Federal intramural performance and growth of 4.0 percent per year for nonprofit organizations (including their FFRDCs).

The 1994–2000 period witnessed dramatic changes in these growth rates. Total R&D performance, in real terms, averaged 5.8 percent growth per year, which was substantially higher than in the earlier sluggish period. Yet, R&D performance at universities and colleges (including their FFRDCs) grew by only 3.1 percent per year in real terms. Industry (including their FFRDCs) grew at a remarkable rate of 7.0 percent in real terms. Federal intramural performance increased by 0.8 percent per year in real terms. Finally, nonprofit organizations (including

Figure 4-10.
National R&D performance, by type of performer: 1953–2000



FFRDCs = Federally Funded Research and Development Centers

See appendix tables 4-3 and 4-4.

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their FFRDCs), according to current estimates, increased their R&D by 5.3 percent per year in real terms over the same six-year period. According to preliminary estimates, these shifts in growth have led, in 2000, to academia (including FFRDCs) representing 13.6 percent of total U.S. R&D performance; Federal intramural activities, 7.2 percent; other nonprofit organizations (including FFRDCs), 3.6 percent; and private industry (including FFRDCs), 75.6 percent. (For level of expenditures in 2000, see text table 4-1.)

Federal R&D Performance

The Federal Government performed $19.1 billion of total U.S. R&D in calendar year 2000, a 2.3 percent rise in real terms from its 1999 level of $18.3 billion. Among the individual agencies, DOD has continued to perform the most intramural R&D; in fact, in FY 2001 it performed more than twice the R&D of the second largest R&D-performing agency, HHS (whose intramural R&D is performed primarily by NIH). (See text table 4-3.) However, DOD's intramural R&D performance has grown by less than 1 percent per year in real terms since FY 1980, reaching a level of $8.6 billion in FY 2001. Furthermore, an undetermined amount of DOD's intramural R&D ultimately appears to be contracted out to other extramural performers. NASA's intramural R&D has grown by 1.4 percent per year in real terms since 1980, to $2.5 billion in FY 2001, and HHS intramural performance rose by 4.0 percent to $3.7 billion. Together, these three agencies account for 76.2 percent of the total ($19.4 billion) Federal intramural R&D in FY 2001.

Total R&D performed by industrial, academic, and nonprofit FFRDCs reached $9.3 billion in calendar year 2000, which is essentially the same as its level of $9.0 billion in 1999 after adjusting for inflation. R&D at FFRDCs in 2000 represented 3.5 percent of the national R&D effort, most of which ($5.8 billion in 2000) was accounted for by university- and college-administered FFRDCs.

R&D in Nonprofit Organizations

A recent NSF survey has led to upward revisions in R&D performance estimates for the nonprofit sector (NSF 2001d). Based on a survey of FY 1996 and FY 1997 R&D at nonprofit organizations and on other available data for the past three years, R&D performance by nonprofit organizations is expected to reach $8.8 billion in 2000, reflecting an average annual growth of 5.5 percent, in real terms, since 1990. Such growth, however, varies considerably by source of funding. The average annual real growth in nonprofit intramural R&D over the same period was 8.0 percent for nonprofit R&D supported by nonprofit organizations themselves, 7.1 percent for nonprofit R&D supported by industry, and 3.5 percent for nonprofit R&D supported by the Federal Government.

Like the Federal Government, nonprofit organizations in recent decades have focused largely on medical and health

Text table 4-6.
Intramural R&D performance at nonprofit organizations, by type of organization and S&E field: FYs 1973 and 1997
(Millions of dollars)

Organization type	Total	Life sciences: Biological sciences	Life sciences: Agricultural sciences	Life sciences: Medical and health sciences	Psychology	Environmental and earth sciences	Physical sciences	Mathematics and computer sciences	Engineering	Social sciences	Other sciences
1973											
Total	786	162	167	26	30	19	72	37	136	130	5
Research institutes	487	104	44	11	18	9	50	34	98	113	5
Hospitals	163	40	98	6	5	0	5	2	2	6	—
Professional or technical societies	62	5	17	4	—	5	13	—	15	2	0
Private foundations	14	5	1	—	—	2	2	0	0	2	0
Science exhibitors	8	4	—	0	—	2	1	0	0	2	0
Trade associations	26	2	0	0	0	1	2	—	20	1	0
Other nonprofit organizations	26	3	7	5	6	0	0	—	—	4	0
1997											
Total	7,349	854	22	4,413	70	232	255	269	490	325	419
Research institutes	4,839	794	11	2,618	65	97	147	263	458	305	83
Hospitals	1,428	20	0	1,408	—	0	0	1	0	0	0
University-affiliated hospitals	464	0	0	463	0	0	0	1	0	0	0
Other voluntary nonprofit hospitals	965	20	0	945	—	0	0	0	0	0	0
Private foundations	458	28	11	386	4	2	11	3	—	10	2
Other nonprofit organizations[a]	624	13	1	2	0	133	97	2	32	10	334

— = Less than $0.5 million

[a]Other nonprofit organizations include professional and technical societies, academies of science or engineering, science exhibitors, academic consortia, industrial consortia, and trade associations.

NOTE: Details may not add to totals because of rounding.

SOURCES: National Science Foundation, Division of Science Resources Studies (NSF/SRS), *R&D Activities of Independent Nonprofit Institutions* (Washington, DC, 1973); and NSF/SRS, *Research and Development Funding and Performance by Nonprofit Organizations: Fiscal Years 1996 and 1997,* Early Release Tables. Available at: <http://www.nsf.gov/sbe/srs/srs01411/start.htm>.

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sciences. (See text table 4-6.) In 1973, only 3.3 percent of all R&D performed by nonprofit organizations was in medical and health sciences, but this share rose dramatically to 60 percent by 1997. In contrast, the agricultural sciences share of intramural nonprofit R&D fell from 21.3 percent in 1973 to 0.3 percent in 1997.

Recent Growth in Industrial R&D, by Sector, Firm Size, and R&D Intensity

R&D performance by private industry reached $199.9 billion in 2000, including $2.6 billion spent by FFRDCs administered by industrial firms. This total represents a 7.1 percent real increase over the 1999 level of $82.8 billion, which, in turn, reflects a smaller, although still noteworthy, real gain of 6.5 percent over 1998. In 2000, R&D performed by industry that was not federally financed rose 8.6 percent in real terms above the 1999 level. Overall, private companies (excluding industry-administered FFRDCs) funded 90.0 percent ($177.6 billion) of their 2000 R&D performance, with the Federal Government funding nearly all the rest ($19.6 billion, or 10 percent of the total).

In recent times, the greatest share of R&D in the United States has been performed by private industry through private industry's own funds.[17] This component of U.S. R&D has grown in importance, from 44 percent of total R&D in 1953, to 49 percent in 1980, to 55 percent in 1990, and 68 percent in 2000. The underlying causes for industry's growing share of R&D financing are complex. In part, the growth may be due to changes in Federal support in areas such as defense and space exploration. Other factors include S&E success stories in specific fields, such as information technology (IT) and biotechnology, in which industry plays a dominant role.

R&D in Manufacturing Versus Nonmanufacturing Industries

Until the 1980s, little attention was paid to R&D conducted by nonmanufacturing companies largely because service-sector R&D activity was negligible compared with the R&D operations of companies classified in manufacturing industries. Before 1983, nonmanufacturing industries accounted for less than 5 percent of the industry R&D total (including industrial FFRDCs), but by 1999 (the most current year for data on industrial sectors), it had reached 36.0 percent. In 1999, nonmanufacturing firms' R&D performance totaled $65.9 billion ($60.4 billion in funds provided by companies and other non-Federal sources and $5.5 billion in Federal support).

Beginning with the 1999 cycle, statistics from NSF's Survey of Industrial R&D have been published using the North American Industrial Classification System (NAICS). (See text table 4-7.) The development of NAICS has been a joint effort of statistical agencies in Canada, Mexico, and the United States. The system replaces the standard industrial classification (SIC) (1980) of Canada, the Mexican Classification of Activities and Products (1994), and SIC (1987) of the United States. NAICS was designed to provide a production-oriented system under which economic units with similar production processes are classified in the same industry. NAICS was developed with special attention to classifications for new and emerging industries, service industries, and industries that produce advanced technologies. NAICS eases comparability of information about the economies of the three North American countries and also increases comparability with the two-digit level of the United Nations International Standard Industrial Classification system (ISIC Revision 3).

Among manufacturers, the new computer and electronic products classification (NAICS 334) includes makers of computers and peripherals, semiconductors, and navigational and electromedical instruments. Among nonmanufacturing industries are information (NAICS 51) and professional, scientific, and technical services (NAICS 54). Information includes publishing (both paper and electronic), broadcasting, and telecommunications. Professional, scientific, and technical services include a variety of industries. Of specific importance for the survey are engineering and scientific R&D services (NSF 2001e).

Following these recent changes in classification, much of the historical data on R&D that had been subdivided according to the previous industrial categories cannot be reclassified into the current industrial categories. As a result, some of trends in the data by industrial category can no longer be observed after 1998 and must be started again, according to different groupings, in 1999. On the other hand, general patterns of change among major sectors are still identifiable. The most striking change in industrial R&D performance during the past two decades is the nonmanufacturing sector's increased prominence.

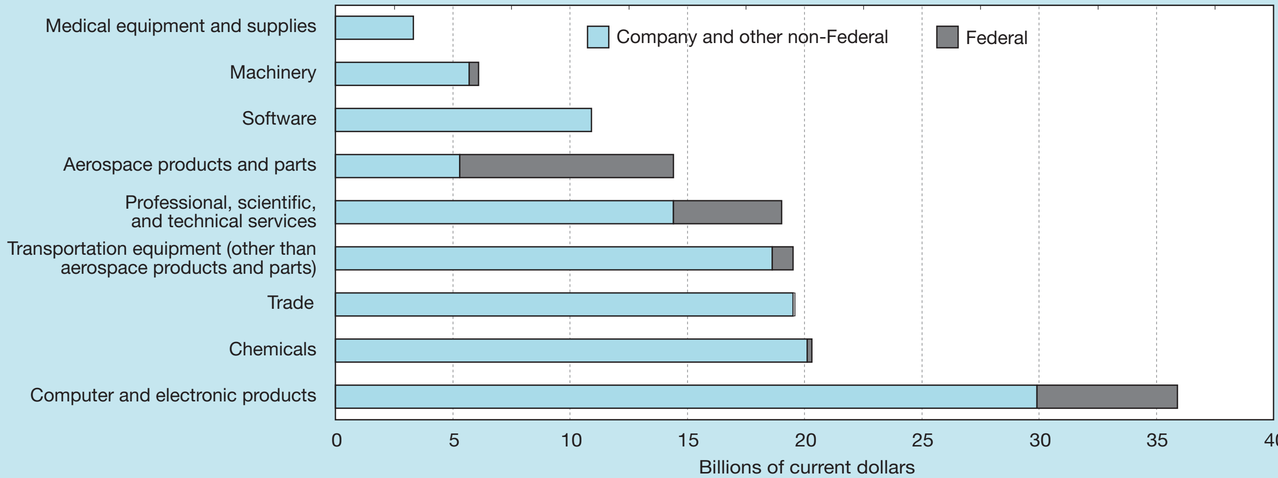
In 1999, the largest nonmanufacturing industry in the performance of R&D was trade (as it is classified in NAICS), which accounted for 10.7 percent of all industrial R&D performance. This was followed closely by professional, scientific, and technical services, accounting for another 10.4 percent of the total, then information, accounting for 8.4 percent.

Within the manufacturing industrial sector (including industry-administered FFRDCs associated with manufacturing), three subsectors dominate: computer and electronic products, transportation equipment, and chemicals. (See figure 4-11 and text table 4-7.) Under the new NAICS system of classification, the computer and electronic products sector accounted for the largest amount of R&D performed in 1999 among all industrial sectors—$35.9 billion. It accounted for 19.7 percent of all industrial R&D (including industry FFRDCs), as well as 14.7 percent of the entire nation's R&D, performed in 1999. Consequently, it exceeded the total amount of R&D performed in 1999 by all universities and colleges and their administered FFRDCs combined (which is only $34.1 billion). For this sector, industrial firms provided $29.9 billion in R&D support; the Federal Government funded the remainder.

Transportation equipment was a close second among the manufacturing sectors in R&D performed in 1999 with $34 billion in R&D, representing 18.6 percent of all industrial

[17]Some of this funding is supported through venture capital investments. For a discussion of the relationship between venture capital and R&D expenditures, see chapter 6.

Figure 4-11.
Industrial R&D performance for selected industries, by source of funds: 1999



See appendix tables 4-31, 4-32, and 4-33. *Science & Engineering Indicators – 2002*

R&D (including R&D by industry-administered FFRDCs). Of these expenditures, 29.6 percent was federally funded, primarily for R&D on aerospace products (planes, missiles, and space vehicles). In addition to aerospace products, the sector includes a variety of other forms of transportation equipment, such as motor vehicles, ships, military armored vehicles, locomotives, and smaller vehicles like motorcycles, bicycles, and snowmobiles (U.S. OMB 1997).

Ranking third in R&D is chemicals, with $20.2 billion in 1999, for which less than 1 percent was federally funded. This sector includes the subsectors pharmaceuticals and medicines (61.0 percent of non-Federal R&D funding in the chemical sector); basic chemicals (13.2 percent); resin, synthetic rubber, fibers, and filament (11.1 percent); and other chemicals (14.7 percent).

Although a great deal of R&D in the United States is related in some way to health care services, companies specifically categorized in the health care services sector accounted for only 0.4 percent of all industrial R&D and for only 1.0 percent of all R&D by nonmanufacturing companies. These results illustrate that R&D data disaggregated according to industrial categories (including the distinction between manufacturing and nonmanufacturing industries) may not always reflect the relative proportions of R&D devoted to particular types of scientific or engineering objectives, or to particular fields of science or engineering.[18] The section "Cross-Sector Field-of-Science Classification Analysis" compensates to some extent for this limitation in the data by providing R&D expenditure levels associated with the broadly defined fields of life sciences and chemistry.

As a case in point, firms that perform R&D under contract to other firms are, by definition, in the service sector because the R&D they perform is, in fact, their "product," which is a service as opposed to manufactured goods. However, they often perform R&D under contract with a manufacturer, implying that those same R&D activities would have been classified as R&D in manufacturing if the same research firm were a subsidiary of the manufacturer. This is counterintuitive in that it implies that whether R&D is in manufacturing or in services is determined, in part, not by physical aspects of the R&D actions themselves but by the labels that have been placed on the firms that perform the R&D. Consequently, a growth in measured R&D in services may, in part, "reflect a more general pattern of industry's increasing reliance on outsourcing and contract R&D" (Jankowski 2001b).

R&D Spending by U.S. Corporations

In 1998, the top 20 U.S. corporations in R&D expenditures spent $54.0 billion on R&D. General Motors reported the most R&D in 1998 with $7.9 billion, followed by another company in the motor vehicle sector, Ford Motor Company, with $6.3 billion. (See text table 4-8.) The rest of the list is dominated by computers, electronic equipment, and software companies, and by pharmaceutical corporations.

Between 1996 and 1998, the total number of publicly held U.S. corporations reporting R&D spending fell from 3,256 to 3,028, although some of this decline is attributable to mergers among existing firms. The decline in the number of firms was not uniform across industrial sectors. For example, the aircraft, guided missiles, and space vehicles sector, which is characterized by relatively large corporations, included exactly 21 corporations in each of the three years. Similarly, the motor vehicles and surface transportation sector went down in number by only 1, from 71 to 70 corporations. This was due to the acquisition of Chrysler Corporation by the German firm Daimler-Benz, which removed Chrysler from the list of U.S. corporations performing R&D (although the R&D

[18]For a more detailed discussion of limitations in the interpretation of R&D levels by industrial categorization, see Payson (2000).

Text table 4-7.
Industrial R&D performance, by industry and source of funding: 1999
(Millions of dollars)

Industry	NAICS code	Total R&D	Company funded	Federally funded	Percent federally funded
All industries	21–23, 31–33, 42, 44–81	182,823	160,288	22,535	12.3
Manufacturing	31–33	116,921	99,865	17,055	14.6
Food	311	1,132	1,132	0	0.0
Beverage and tobacco products	312	D	D	0	NA
Textiles, apparel, and leather	313–16	334	334	0	0.0
Wood products	321	70	70	0	0.0
Paper, printing, and support activities	322, 323	D	2,474	D	NA
Petroleum and coal products	324	615	D	D	NA
Chemicals	325	20,246	20,051	194	1.0
Basic chemicals	3251	2,746	2,648	98	3.6
Resin, synthetic rubber, fibers, and filament	3252	D	2,216	D	NA
Pharmaceuticals and medicines	3254	D	12,236	D	NA
Other chemicals	325 minus (3251–52, 3254)	D	2,951	D	NA
Plastics and rubber products	326	1,785	1,785	0	0.0
Nonmetallic mineral products	327	D	595	D	NA
Primary metals	331	470	457	12	2.6
Fabricated metal products	332	1,655	1,608	46	2.8
Machinery	333	6,057	5,658	399	6.6
Computer and electronic products	334	35,932	29,939	5,993	16.7
Computers and peripheral equipment	3341	D	4,126	D	NA
Communications equipment	3342	6,003	5,797	206	3.4
Semiconductor and other electronic components	3344	10,701	10,624	77	0.7
Navigational, measuring, electromedical, and control instruments	3345	14,337	8,632	5,705	39.8
Other computer and electronic products	334 minus (3341–42, 3344–45)	D	760	D	NA
Electrical equipment, appliances, and components	335	D	3,820	D	NA
Transportation equipment	336	33,965	23,928	10,037	29.6
Motor vehicles, trailers, and parts	3361–63	D	17,987	D	NA
Aerospace products and parts	3364	14,425	5,309	9,117	63.2
Other transportation equipment	336 minus (3361–64)	D	632	D	NA
Furniture and related products	337	248	248	0	0.0
Miscellaneous manufacturing	339	3,851	3,825	26	0.7
Medical equipment and supplies	3391	D	3,251	D	NA
Other miscellaneous manufacturing	339 minus 3391	D	574	D	NA
Small manufacturing companies[a]	<50 employees	3,019	2,950	69	2.3
Nonmanufacturing	21–23, 42, 44–81	65,902	60,423	5,479	8.3
Mining, extraction, and support activities	21	D	2,352	D	NA
Utilities	22	142	126	17	12.0
Construction	23	691	690	2	0.3
Trade	42, 44, 45	19,616	19,521	95	0.5
Transportation and warehousing	48, 49	460	460	0	0.0
Information	51	15,389	14,892	497	3.2
Publishing	511	11,302	11,253	49	0.4
Newspaper, periodical, book, and database	5111	371	371	0	0.0
Software	5112	10,931	10,882	49	0.4
Broadcasting and telecommunications	513	D	1,393	D	NA
Other information	51 minus (511, 513)	D	2,246	D	NA
Finance, insurance, and real estate	52, 53	D	1,570	D	NA
Professional, scientific, and technical services	54	18,994	14,379	4,615	24.3
Architectural, engineering, and related services	5413	3,580	2,402	1,177	32.9
Computer systems design and related services	5415	D	3,989	D	NA
Scientific R&D services	5417	10,470	7,413	3,057	29.2
Other professional, scientific, and technical services	54 minus (5413, 5415, 5417)	D	575	D	NA
Management of companies and enterprises	55	D	72	D	NA
Health care services	621–23	642	631	10	1.6
Other nonmanufacturing	56, 61, 624, 71, 72, 81	D	752	D	NA
Small nonmanufacturing companies[a]	<15 employees	5,203	4,977	227	4.3

NAICS = North American Industry Classification System; D = data withheld to avoid disclosing operations of individual companies; NA = not available

[a]The frame from which the statistical sample was selected was divided into two partitions based on total company employment. In the manufacturing sector, companies with employment of 50 or more were included in the large company partition. In the nonmanufacturing sector, companies with employment of 15 or more were included in the large company partition. Companies in the respective sectors with employment below these values, but with at least 5 employees, were included in the small company partition. The purpose of partitioning the sample this way was to reduce the variability in industry estimates largely attributed to the random year-to-year selection of small companies by industry and the high sampling weights that sometimes were assigned to them. Because of this, detailed industry statistics were possible only from the large company partition. Statistics from the small company partition are shown separately and are included in manufacturing, nonmanufacturing, and all industries totals.

SOURCE: National Science Foundation, Division of Science Resources Studies (NSF/SRS), *Research and Development in Industry: 1999,* Early Release Tables (Arlington, VA, 2001)

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Text table 4-8.
Top 20 R&D spending corporations: 1998

R&D rank				R&D (billions of dollars)			Percent change from	Sector	
1998	1997	1996	Corporation	1998	1997	1996	1996 to 1998	Major	Detailed
1	1	1	General Motors	7.900	8.200	8.900	–11.2	Motor vehicles and surface transportation	Motor vehicles and motor vehicle equipment
2	2	2	Ford Motor Co.	6.300	6.327	6.821	–7.6	Motor vehicles and surface transportation	Motor vehicles and motor vehicle equipment
3	3	3	Intl. Business Machines	4.466	4.307	3.934	13.5	Information and electronics	Multiple and miscellaneous computer and data processing services
4	4	7	Lucent Technologies	3.678	3.101	1.838	100.1	Information and electronics	Modems and other wired telephone equipment
5	5	4	Hewlett-Packard	3.355	3.078	2.718	23.4	Information and electronics	Electronic computers and computer terminals
6	6	5	Motorola	2.893	2.748	2.394	20.8	Information and electronics	Radio, TV, cell phone, and satellite communications equipment
7	7	8	Intel	2.509	2.347	1.808	38.8	Information and electronics	Electronic components (e.g., semiconductors, coils)
8	10	11	Microsoft	2.502	1.925	1.432	74.7	Information and electronics	Prepackaged software
9	9	9	Pfizer	2.279	1.928	1.684	35.3	Medical substances and devices	Drugs: pharmaceutical preparations
10	8	6	Johnson & Johnson	2.269	2.140	1.905	19.1	Medical substances and devices	Drugs: pharmaceutical preparations
11	11	18	Boeing	1.895	1.924	1.200	57.9	Aircraft, guided missiles, and space vehicles	Aircraft, guided missiles, and space vehicles
12	12	10	Merck & Company	1.821	1.684	1.487	22.4	Medical substances and devices	Drugs: pharmaceutical preparations
13	16	19	Eli Lilly & Company	1.739	1.382	1.190	46.2	Medical substances and devices	Drugs: pharmaceutical preparations
14	13	12	American Home Products	1.655	1.558	1.429	15.8	Medical substances and devices	Drugs: pharmaceutical preparations
15	15	14	Bristol Myers Squibb	1.577	1.385	1.276	23.6	Medical substances and devices	Drugs: pharmaceutical preparations
16	18	16	Procter & Gamble	1.546	1.282	1.221	26.6	Chemicals	Other chemical (e.g., soaps, ink, paints, fertilizers, explosives)
17	14	13	General Electric	1.537	1.480	1.421	8.2	Machinery and electrical equipment	Electrical equipment (industrial and household)
18	NA	NA	Delphi Automotive System	1.400	NA	NA	NA	Motor vehicles and surface transportation	Motor vehicles and motor vehicle equipment
19	31	50	Compaq	1.353	0.817	0.407	232.4	Information and electronics	Electronic computers and computer terminals
20	20	20	United Technologies	1.315	1.187	1.122	17.2	Aircraft, guided missiles, and space vehicles	Aircraft, guided missiles, and space vehicles

NA = not available

SOURCE: Standard & Poor's Compustat (Englewood, CO).

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it performs within the United States is still collected by NSF's industrial R&D survey and included in this chapter's data on U.S. industrial R&D performance).[19] Chrysler was ranked number 12 in U.S. corporations' 1997 R&D spending. In contrast, between 1996 and 1998, the number of R&D-performing corporations fell from 1,477 to 1,382 in the information and electronics sector, from 629 to 566 in the medical substances and devices sector, and from 422 to 386 in the basic industries and materials sector (Shepherd and Payson 2001).

Industrial R&D and Firm Size

Industrial manufacturing R&D performers are typically quite different from industrial nonmanufacturing R&D performers; nonmanufacturing R&D performers tend to be smaller firms. (See text table 4-9.) Approximately 39,000 firms in the United States performed R&D in 1999; of these, 54 percent were in the nonmanufacturing sector. Yet, manufacturers account for 64 percent of total industry R&D performance (including federally funded industry performance). As a share of the nation's GDP, on the other hand, manufacturing accounts for less than 20 percent. The main reason for continued dominance in R&D performance is that among manufacturing firms, the largest in terms of number of employees tend to perform a relatively large amount of R&D. Among small R&D-performing firms (fewer than 500 employees) in both the manufacturing and nonmanufacturing sectors, those in the nonmanufacturing sector tend to conduct twice as much R&D per firm as those in the manufacturing sector. However, among large R&D-performing firms (more than 25,000 employees) in both sectors, those in the manufacturing firms tend to conduct more than 10 times as much R&D per firm as those in the nonmanufacturing sector.

Although R&D tends to be performed by large firms in the manufacturing sector and small firms in the nonmanufacturing sector, within each sector there is consider-

[19] The corporate R&D data were obtained from a source that differs from the NSF *Survey of Industrial Research and Development*; namely, from the *U.S. Corporate R&D* database (see Shepherd and Payson 2001). Consequently, the definition of R&D in this case is not equivalent to that of the NSF industry R&D survey, as indicated in this example about the Chrysler Corporation.

Text table 4-9.
Total funds for industry R&D performance and number of R&D-performing companies in manufacturing and nonmanufacturing industries, by size of company: 1999

Size of company (number of employees)	Total	Manufacturing	Nonmanufacturing
Funds for industrial R&D (millions of dollars)			
Total	182,823	116,921	65,902
5–25	7,004	738	6,265
25–49	4,750	791	3,959
50–99	7,225	2,183	5,042
100–249	7,213	2,623	4,591
250–499	7,892	2,190	5,701
500–999	7,032	3,763	3,269
1,000–4,999	24,840	15,561	9,278
5,000–9,999	16,376	10,893	5,483
10,000–24,999	24,922	18,014	6,908
25,000 or more	75,569	60,163	15,406
Number of R&D-performing companies			
Total	39,005	18,059	20,946
5–25	18,355	5,750	12,606
25–49	6,749	3,707	3,042
50–99	5,102	2,644	2,457
100–249	4,083	2,840	1,243
250–499	1,788	975	813
500–999	1,118	890	228
1,000–4,999	1,157	865	292
5,000–9,999	288	194	94
10,000–24,999	198	129	69
25,000 or more	167	65	102

SOURCE: National Science Foundation, Division of Science Resources Studies (NSF/SRS), *Research and Development in Industry: 1999,* Early Release Tables (Arlington, VA, 2001

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able variation, depending on the type of industry. R&D tends to be conducted primarily by large firms in several industrial sectors: aircraft and missiles, electrical equipment, professional and scientific instruments, transportation equipment (not including aircraft and missiles), and transportation and utilities (which are in the nonmanufacturing sector). On the other hand, in these same sectors much of the economic activity is carried out by large firms to begin with, so the observation that most of the R&D in these sectors is also conducted by large firms is not surprising.

R&D Intensity

In addition to absolute levels of, and changes in, R&D expenditures, another key indicator of the health of industrial S&T is R&D intensity. R&D is similar to sales, marketing, and general management expenses in that it is discretionary, i.e., a nondirect revenue-producing item that can be trimmed when profits are falling. There seems to be considerable evidence, however, that R&D enjoys a high degree of immunity from belt-tightening endeavors, even when the economy is faltering, because of its crucial role in laying the foundation for future growth and prosperity. Nevertheless, whether industry devotes the right amount of economic resources to R&D has remained an open question. See sidebar, "Does Industry Underinvest in R&D?"

There are numerous ways to measure R&D intensity; the one used most frequently is the ratio of R&D funds to net sales.[20] This statistic provides a way to gauge the relative importance of R&D across industries and firms in the same industry. The industrial sectors with the highest R&D intensities in 1999 were scientific R&D services (32.1 percent), software (16.7 percent), communications equipment (11.6 percent), and computer systems design and related services (11.0 percent). Those with the lowest R&D intensities (less than 0.5 percent) were food, primary metals, broadcasting and telecommunications, and utilities. (See text table 4-10.) For all industries combined, the ratio of R&D to sales was 2.7 percent in 1999.

[20]Another measure of R&D intensity is the ratio of R&D to "value added" (which is sales *minus* the cost of materials). Value added is often used in studies of productivity analysis because it allows analysts to focus on the economic output attributable to the specific industrial sector in question by subtracting materials produced in other sectors. For a discussion of the connection between R&D intensity and technological progress, see, for example, Nelson (1988).

Does Industry Underinvest in R&D?

In a recent report by the National Institute for Standards and Technology (Tassey 1999), the author suggests that private industry may be underinvesting in R&D for the following reasons:

- **The riskiness of technology** must be factored in, not only in terms of achieving a technological advance but also in acquiring the ability to market it first. For example, if one firm initiates the research and makes the important discoveries but another firm is able to market the new technology first, then the firm that made the discovery would not recover its costs for R&D. Consequently, even though the economic returns to the second firm in this case would be very high, as would be the economic returns to society, the firm that initiated the effort may have good reason to be skeptical about its expected gains and therefore may be reluctant to initiate the work.
- **Spillovers from the technology** to other industries and to consumers, such as lower prices ("price spillovers") and increased general knowledge ("knowledge spillovers") may bring many benefits to the economy as a whole, independent of the returns to the firm that performs the R&D. As Tassey notes, "To the extent that rates of return fall below the private hurdle rate, investment by potential innovators will not occur."
- **Inefficiencies resulting from market structures,** in which firms may face high costs of achieving comparability when they are competing against each other in the development of technological infrastructure. For example, software developers are constrained, not only by the immediate development task at hand but also in having to ensure that the new software they develop is compatible with software and operating systems that other firms may be developing simultaneously. Here, greater efforts undertaken by industry or government to encourage standardization of emerging technologies would likely lead to higher returns to R&D.
- **Narrow corporate strategies.** According to Tassey, corporate strategies "often are narrower in scope than a new technology's market potential." In other words, companies in one line of business may not realize that the technological advances they make may have beneficial uses in other lines of business.* Thus, broader-based strategies that extend beyond a firm's immediate line of products would yield greater returns to R&D.
- **Large-scale technological infrastructure needs**. Like the Internet, technological infrastructure often yields high returns to individual companies and to the overall economy but often requires substantial levels of investment before any benefits can be realized. This argument is similar to the public-goods argument: for some large-scale R&D projects, funds from either government or an organized collaboration of industry participants may be necessary for the project to achieve the critical mass it needs to be successful. Once it is successful, however, high returns on the R&D invested might be realized.

Among NIST's general goals in addressing these issues is to encourage a "more analytically based and data-driven R&D policy."

*Levitt (1975) referred to this kind of problem as "marketing myopia."
SOURCE: Tassey (1999).

Performance by Geographic Location, Character of Work, and Field of Science

R&D by Geographic Location

The latest data available on the state distribution of R&D performance are for 1999. These data cover R&D performance by industry, academia, and Federal agencies, along with the federally funded R&D activities of nonprofit institutions.[21] In 1999, total R&D expenditures in the United States were $244.1 billion, of which $231.8 billion could be attributed to expenditures within individual states, with the remainder falling under an undistributed, "other/unknown" category. (See appendix tables 4-21 and 4-22.) The statistics and discussion below refer to state R&D levels in relation to the distributed total of $231.8 billion.

[21]For historical data see appendix table 4-22. The state data on R&D contain 52 records: the 50 states; the District of Columbia and "other/unknown," which accounts for R&D in Puerto Rico and other nonstate U.S. regions; and R&D for which the particular state was not known. Approximately two-thirds of the R&D that could not be associated with a particular state is R&D performed by the nonprofit sector.

R&D is substantially concentrated in a small number of states. In 1999, California had the highest level of R&D performed within its borders—$48.0 billion—representing approximately one-fifth of the $231.8 billion U.S. total. The six states with the highest levels of R&D performance, California, Michigan, New York, Texas, Massachusetts, and Pennsylvania (in descending order), accounted for approximately one-half of the entire national effort. (See text table 4-11.) The top 10 states (the six above-mentioned states plus New Jersey, Illinois, Washington, and Maryland) accounted for approximately two-thirds of the national effort. (See appendix table 4-23.) California's R&D performance was 2.5 times as large as the R&D performance of the second highest state, Michigan, at $18.8 billion. After Michigan, ranking third was New York, with $14.1 billion, and the lowest of the top 10 states, Maryland, had $8.1 billion in R&D. The 20 highest ranking states in R&D expenditures accounted for 86.0 percent of the U.S. total; the lowest 20 states accounted for 4.5 percent.

Text table 4-10.
Company and other (non-Federal) R&D funds as percentage of net sales in R&D-performing companies for selected industries: 1999

Industry	R&D as a percentage of sales
All industries	2.7
Manufacturing	3.2
Communications equipment	11.6
Pharmaceuticals and medicines	10.5
Navigational, measuring, electromedical, and control instruments	9.1
Semiconductor and other electronic components	8.3
Medical equipment and supplies	7.7
Computers and peripheral equipment	6.4
Resin, synthetic rubber, fibers, and filament	4.2
Machinery	3.3
Other chemicals	3.2
Aerospace products and parts	3.2
Motor vehicles, trailers, and parts	2.9
Electrical equipment, appliances, and components	2.3
Basic chemicals	2.0
Plastics and rubber products	1.9
Nonmetallic mineral products	1.5
Paper, printing and support activities	1.4
Fabricated metal products	1.4
Textiles, apparel, and leather	0.7
Furniture and related products	0.7
Wood products	0.5
Food	0.4
Primary metals	0.4
Nonmanufacturing	2.2
Scientific R&D services	32.1
Software	16.7
Computer systems design and related services	11.0
Architectural, engineering, and related services	6.8
Health care services	6.4
Management of companies and enterprises	5.7
Trade	5.5
Construction	3.1
Newspaper, periodical, book, and database information	2.0
Mining, extraction, and support activities	1.9
Finance, insurance, and real estate	0.5
Transportation and warehousing	0.5
Broadcasting and telecommunications	0.4
Utilities	0.1

SOURCE: National Science Foundation, Division of Science Resources Studies (NSF/SRS), *Research and Development in Industry: 1999,* Early Release Tables (Arlington, VA, 2001)

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States vary widely in the size of their economies because of differences in population, land area, infrastructure, natural resources, and history. Consequently, variation in the R&D expenditure levels of states may simply reflect differences in their economic size or the nature of their R&D efforts. A basic way of controlling for this “size effect” is to measure each state’s R&D level as a proportion of its gross state product (GSP). (See appendix table 4-23.) Like the term used in reference to the ratio of industrial R&D to sales, the proportion of a state’s GSP devoted to R&D is referred to as R&D “intensity” or “concentration.” Overall, the nation’s total R&D to GDP ratio in 1999 was 2.63 percent. The top 10 rankings for R&D intensity were, in descending order, New Mexico (6.4 percent), Michigan (6.1 percent), Rhode Island (5.1 percent), Massachusetts (4.6 percent), Maryland (4.6 percent), the District of Columbia (4.5 percent), Washington (4.0 percent), California (3.9 percent), Delaware (3.9 percent), and Idaho (3.8 percent).

States have always varied in terms of the levels and types of industrial operations they contain. Thus, they also vary in the levels of R&D they contain by industrial sector. One measure of such variation among states is the extent to which their industrial R&D is in the manufacturing sector as opposed to the nonmanufacturing sector. Among the top 10 states in 1999 in industrial R&D performance, California, Massachusetts, Ohio, Texas, and Washington all had relatively low shares of R&D in the manufacturing sector (less than 64 percent, which was the national average). Higher levels of R&D in manufacturing, as a percentage of the total, were observed for Illinois, Michigan, New Jersey, New York, Ohio, and Pennsylvania. Among these 10 states, Michigan had the highest ratio of 92 percent, and Texas had the lowest ratio of 40 percent (industrial R&D in the manufacturing sector as a percentage of total industrial R&D). Part of this variation is attributable to differences among states in terms of their relative proportions of manufacturing and nonmanufacturing industries. Michigan, for example, is concentrated in motor vehicle manufacturing, and California devotes a great deal of R&D to software development and agricultural research. In Texas, 25 percent of industrial R&D performance took place in its computer and electronic products sector and another 20 percent in mining and extraction (including drilling for petroleum). Other factors, besides the locations of industrial production, may also play a role. For example, industries tend to perform research near universities that conduct the same type of research, enabling them to benefit from local academic resources.

Trends in National R&D by Character of Work

One traditional way to analyze trends in R&D performance is to examine the amount of funds devoted to basic research, applied research, and development. Admittedly, the traditional categories of basic research, applied research, and development do not always ideally describe the complexity of the relationship between science, technology, and innovation. However, alternative and perhaps more realistic models of the innovation process are probably too complicated to be used in collecting and analyzing comparable and reliable data for policymaking purposes and would not enable time-series analyses. See sidebar, “Choice of Right R&D Taxonomy Is a Historical Concern,” later in the chapter. Nonetheless, in spite of these analytical limitations, these categories generally are useful to characterize the relative expected time horizons and types of investments.

The nation spent $47.9 billion on the performance of basic research in 2000, $55.0 billion on applied research and $161.7 billion on development. (See text table 4-1.) These totals are the result of continuous increases over several years. Namely,

Text table 4-11.
R&D performance by sector and R&D as percentage of GSP, for top 10 R&D performing states: 1999

Rank	Total R&D (millions of dollars)	Top 10 states in R&D performance, by performing sector: All R&D performers in state	Industry[a]	Universities and colleges[b]	Federal Government	Top 10 states in R&D intensity (states with highest R&D/GSP ratio): Top 10 states	R&D/GSP (percent)	GSP (billions of dollars)
1	47,965	California	California	California	Maryland	New Mexico	6.43	51.0
2	18,799	Michigan	Michigan	New York	District of Columbia	Michigan	6.10	308.3
3	14,110	New York	New York	Texas	Virginia	Rhode Island	5.07	32.5
4	12,429	Texas	Texas	Massachusetts	California	Massachusetts	4.64	262.6
5	12,190	Massachusetts	New Jersey	Pennsylvania	Alabama	Maryland	4.63	174.7
6	10,695	Pennsylvania	Massachusetts	Maryland	Florida	District of Columbia	4.50	55.8
7	10,536	New Jersey	Pennsylvania	Illinois	Ohio	Washington	3.98	209.3
8	9,719	Illinois	Illinois	North Carolina	Texas	California	3.90	1,229.1
9	8,336	Washington	Washington	Michigan	New Jersey	Delaware	3.87	34.7
10	8,087	Maryland	Ohio	Georgia	New Mexico	Idaho	3.85	34.0

GSP = gross state product

[a]Includes R&D expenditures of federally funded research and development centers (FFRDCs) administered by industry.

[b]Includes total R&D expenditures of FFRDCs administered by academic institutions.

SOURCE: National Science Foundation, Division of Science Resources Studies (NSF/SRS), *National Patterns of R&D Resources: 2000 Data Update,* NSF 01-309 (Arlington, VA, March 2001). Available at <http://www.nsf.gov/sbe/srs/nsf01309/start.htm>.

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since 1980 they reflect a 5.5 percent annual increase, in real terms, for basic research; a 3.9 percent increase for applied research; and a 3.8 percent increase for development. As a share of all 2000 R&D performance expenditures, basic research represented 18.1 percent, applied research represented 20.8 percent, and development represented 61.1 percent. These shares have not changed very much over time. For example, in 1980 basic research accounted for 13.9 percent, applied research accounted for 21.7 percent, and development accounted for 64.3 percent.

Basic Research. In terms of support, the Federal Government has always provided the majority of funds used for basic research. (See figure 4-12.) However, its share of funding for basic research as a percentage of all funding has fallen substantially, from 70.5 percent in 1980 to 48.7 percent in 2000. This decline in the Federal share of basic research support does not reflect a decline in the actual amount of Federal support, which, in fact, grew 3.5 percent per year in real terms between 1980 and 2000. Rather, it reflects a growing tendency for the funding of basic research to come from other sectors. From 1980 to 2000, industry's self-reported support for basic research grew at the rate of 10.0 percent per year in real terms.

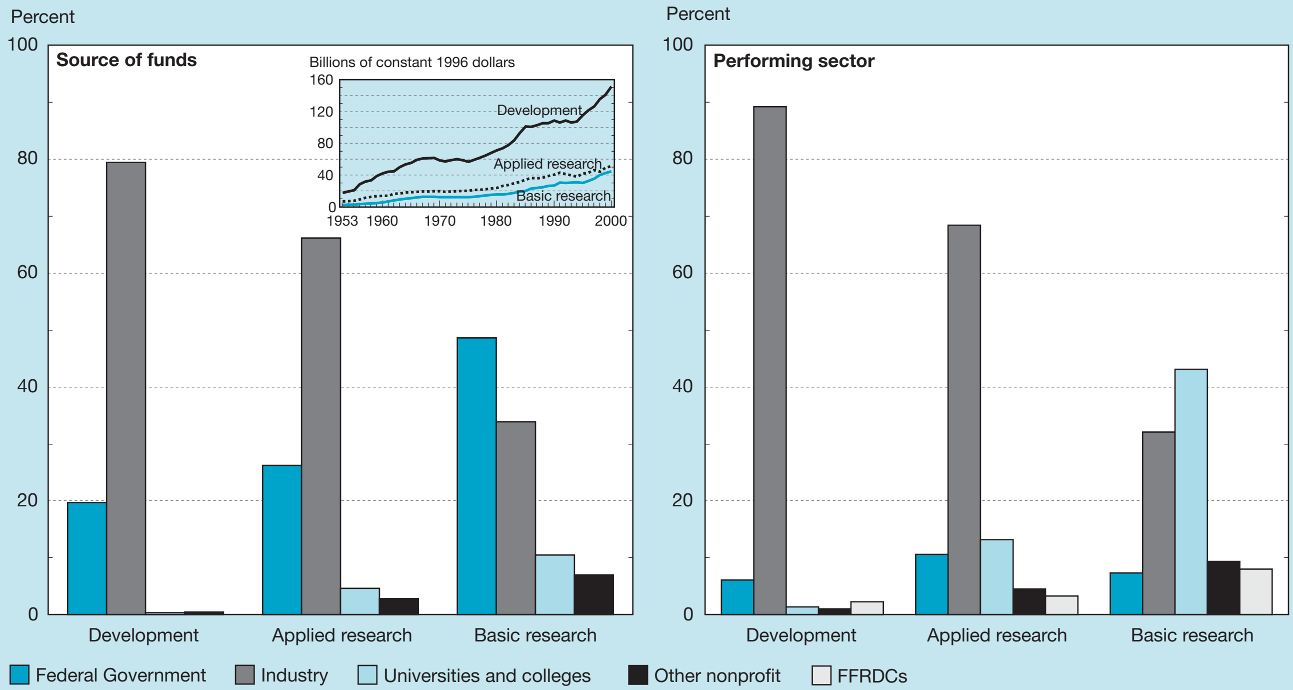
With regard to the performance of basic research in 2000, universities and colleges (excluding FFRDCs) accounted for the largest share with 43.1 percent ($20.7 billion), followed by industry with 32.1 percent ($15.4 billion). Their performance of basic research has undergone, on average, a 4.8 percent real annual increase since 1980. University-administered FFRDCs accounted for another 5.9 percent of total basic research performance in 2000. The dominant role played by universities and colleges in basic research is clearly related to the leading role that universities have in expanding general knowledge of S&E. Along the lines that general knowledge of science is a public good, the Federal Government provided 58.0 percent of the funding for basic research performed by universities and colleges. Non-Federal sources (industry, state and local governments, universities and colleges, and non-profit organizations) provided the remaining 42.0 percent.

Applied Research. Applied research expenditures total $55.0 billion in 2000 and are performed much more by non-academic institutions. They have been subject to greater shifts over time because of fluctuations in industrial growth and Federal policy. Applied research experienced a substantial average annual real growth of 7.4 percent between 1980 and 1985, followed by very low growth of 1.1 percent between 1985 and 1994, then rose again to 5.1 percent between 1994 and 2000. Increases in industrial support for applied research explain this recent upturn. Industrial support accounts for 66.1 percent ($36.4 billion) of the 2000 total for applied research and Federal support for 26.3 percent ($14.5 billion).

In the past two decades, Federal support for applied research has been intentionally deemphasized in favor of basic research. Consequently, in 2000 Federal funding for applied research is only 62.0 percent of that for basic research ($14.5 billion versus $23.3 billion, respectively), as reported by research performers.

Most applied research in calendar year 2000 (68.4 percent, or $37.6 billion) was performed by industry. In the same year, most of the nation's nonindustrial applied research was performed by universities and colleges and their administered FFRDCs ($8.7 billion) and the Federal Government ($5.8 billion). For Federal intramural applied research (for which data are organized by fiscal year), 24.7 percent in FY 2000 was

Figure 4-12.
National R&D expenditures, by source of funds, performing sector, and character of work: 2000



FFRDCs = Federally Funded Research and Development Centers

See appendix tables 4-7 through 4-18.

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performed by HHS, 21.8 percent in FY 2000 was performed by DOD, and 11.6 percent was performed by DOC. Total Federal applied research performance has been remarkably level for 34 years, experiencing only a 0.8 percent average annual growth, in real terms, since 1966.

Development. Expenditures on development in calendar year 2000 totaled $161.7 billion, accounting for most of R&D expenditures. Therefore, historical patterns of development expenditures mirror historical patterns of total R&D expenditures. From 1980 to 1985, development grew on average by 7.2 percent per year in real terms as increasingly larger shares of the national R&D effort were directed toward R&D supported by DOD, which tends to be approximately 90 percent development. (See figure 4-13.) Between 1985 and 1994, on the other hand, development in real terms grew at an average annual rate of only 0.7 percent, from $74.5 billion in 1985 to $103.0 billion in 1994. Between 1994 and 2000, annual growth was back up to 5.9 percent in real terms to $161.7 billion in 2000, of which 79.4 percent was supported by industry and 19.7 percent by the Federal Government.

In terms of performance, industry accounted for 89.2 percent ($144.3 billion) of the nation's 2000 development activities, the Federal Government 6.1 percent ($9.8 billion), and all other performers 4.7 percent ($7.6 billion).

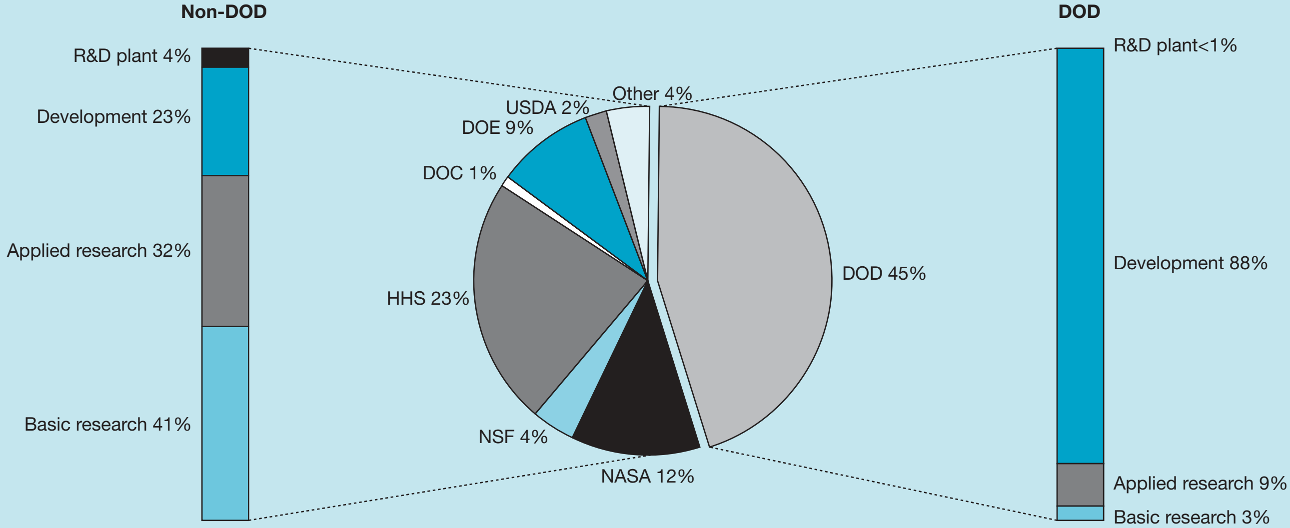
Federal Obligations for Research, by Field

Federal obligations for research alone (excluding development) will total $38.7 billion in FY 2001 by preliminary estimates. Life sciences will receive the largest portion of this funding (47.2 percent, or $18.2 billion), most of which will be provided by HHS. (See figure 4-14.) The next largest field in Federal obligations for research in FY 2001 will be engineering (18.3 percent), followed by physical sciences (11.5 percent), environmental sciences (8.4 percent), and mathematics and computer sciences (6.5 percent). Social sciences, psychology, and all other sciences will account for another 2.6 percent, 1.9 percent, and 3.6 percent, respectively.

In terms of agency contributions to these research efforts, HHS, primarily through NIH, will provide the most (42.8 percent) of all Federal research obligations in FY 2001. The next largest contributor will be NASA (12.2 percent) with substantial funding of research in engineering ($2.2 billion), physical sciences ($0.9 billion), and environmental sciences ($1.1 billion). (See figure 4-14.) DOE will provide 11.7 percent of research funding, primarily in the fields of engineering, physical sciences, and mathematics and computer sciences. DOD will fund a similar amount of research (11.4 percent of the total), primarily in the areas of engineering and mathematics and computer sciences. NSF will provide 8.2 percent of research funding, with between $0.5 and $0.7 billion contributed to each of the following fields: life sciences, engineering, physical sciences, environmental sciences, and mathematics and computer sciences.

Federal obligations for research have grown at different rates for different fields of S&E, reflecting changes in perceived public interest in those fields, changes in the national

Figure 4-13.
Projected Federal obligations for R&D and R&D plant, by agency and character of work: FY 2001



DOC = Department of Commerce; DOE = Department of Energy; DOD = Department of Defense; HHS = Department of Health and Human Services; NSF = National Science Foundation; NASA = National Aeronautics and Space Administration; USDA = U.S. Department of Agriculture

See appendix table 4-25.

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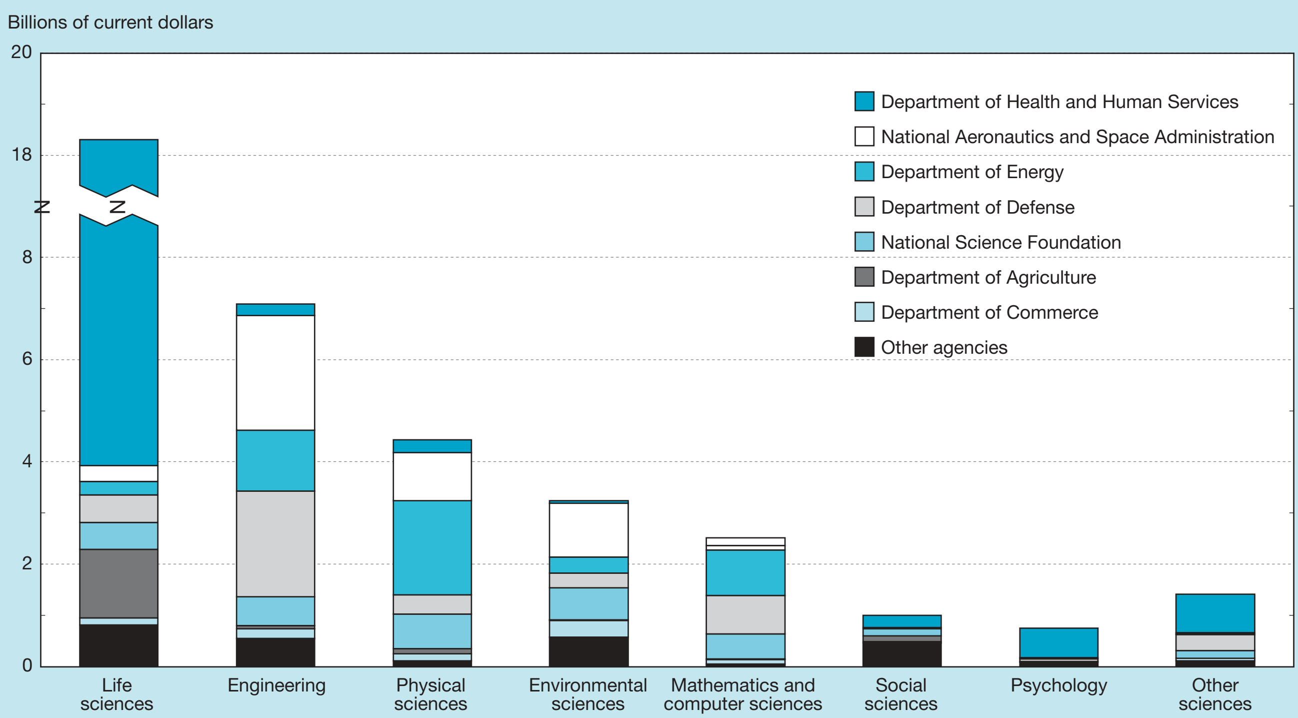
Figure 4-14.
Federal obligations for research, by major science and engineering field, and agency: FY 2001



See appendix table 4-27.

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resources (e.g., scientists, equipment, and facilities) that have been built up in those fields over time, as well as differences in scientific opportunities across fields. Based on preliminary estimates for FY 2001, the broad field of mathematics and computer sciences has experienced the highest rate of growth in Federal obligations for research, which was 8.3 percent per year in real terms between 1980 and 2001. Life sciences had the second highest rate with 3.9 percent, followed by psychology with 3.2 percent, environmental sciences with 1.3 percent, engineering with 1.2 percent, and physical sciences with 0.6 percent. Research in the social sciences (including anthropology, economics, political sciences, sociology, and other areas) experienced a slight decline of 0.12 percent.

These trends in Federal support for the above-mentioned broad fields of research, however, may not reflect trends for the smaller fields that they contain. For example, with regard to the broad field of mathematics and computer sciences, Federal support for research in mathematics grew by 3.8 percent per year in real terms between FY 1980 and FY 1999, whereas support for research in computer sciences grew by 10.2 percent.[22] During the same period, within life sciences, support for biological and agricultural research grew by 1.7 percent compared with research support for medical sciences, which grew by 4.6 percent. Within the physical sciences, support for astronomy grew by 1.8 percent, whereas support for chemistry declined by 0.23 percent.

Cross-Sector Field-of-Science Classification Analysis

Federal and academic research expenditures are often classified according to the S&E fields they support. However, it may also be useful to classify all R&D activity by specific S&E fields. Such classification, when applied to historical data, would indicate how R&D efforts in various fields of S&E have grown in economic importance over time. This information is potentially useful for science policy analysis and for planning and priority setting.

Classification of academic R&D by field of science is provided in detail in chapter 5. At present, the only additional sector for which there exist extensive data by field is the Federal Government. Industrial R&D, which represents three-fourths of all R&D performed in the United States, is not collected by field of study for three reasons:

- Unlike universities and Federal agencies, most private companies do not have the recordkeeping infrastructure in place to compile such statistics; thus, any efforts on their part to provide this additional information could be significantly burdensome to them.
- Much of the research by private firms is confidential, and the provision of such information to outsiders might compromise that confidentiality.
- Much of the R&D carried out by industry is interdisciplinary, especially at the development stage (e.g., the development of a new vehicle would involve mechanical engineering, electrical engineering, and other fields), which in many cases might make the splitting of R&D by field somewhat arbitrary.

[22]For these smaller field categories, the latest available data are for FY 1999.

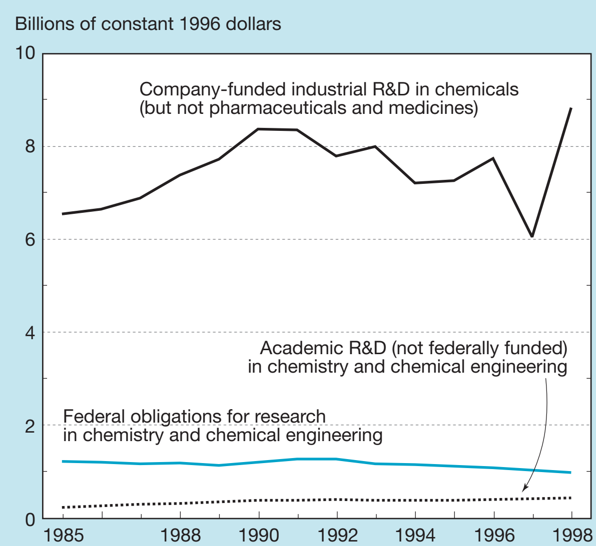
Nonetheless, some analysis by field of study, wherever possible, shed light on overall levels of R&D support for general lines of inquiry. In particular, this problem can be circumvented by grouping fields within standard industrial categories, thereby creating categories of R&D that can be associated both with S&E fields and with related industrial categories. We focus in particular in two broad areas, chemistry (nonmedical) and chemical engineering, and life sciences. For ease in data interpretation, all academic and Federal FY data were converted to calendar year data so that they would be comparable to the data pertaining to industry categories (which are collected and provided on a calendar year basis).[23]

R&D in Chemistry (Nonmedical) and Chemical Engineering. In 1998, R&D in the broad area of chemistry and chemical engineering accounted for approximately $10.3 billion (in constant 1996 dollars). Three categories of R&D were identified in this area.[24] (See figure 4-15.) The largest of these categories, by far, is company-funded R&D in industrial chemicals and other chemicals (but not pharmaceuticals and medicines). In real terms (constant 1996 dollars), expendi-

[23]At this writing, the most recent data on academic R&D performance and Federal R&D obligations are for FY 1999. However, the conversion of these numbers from fiscal year to calendar year meant that only data estimates for calendar year 1998 were possible for these figures because estimation of calendar year 1999 data would have required fiscal year 2000 data, which were not available. All dollar amounts in this section are given in real terms (constant 1996 dollars).

[24]These categories exclude chemistry associated with medicine, which was included instead under life sciences.

Figure 4-15.
R&D associated primarily with chemistry (nonmedical) and chemical engineering



See appendix table 4-28.

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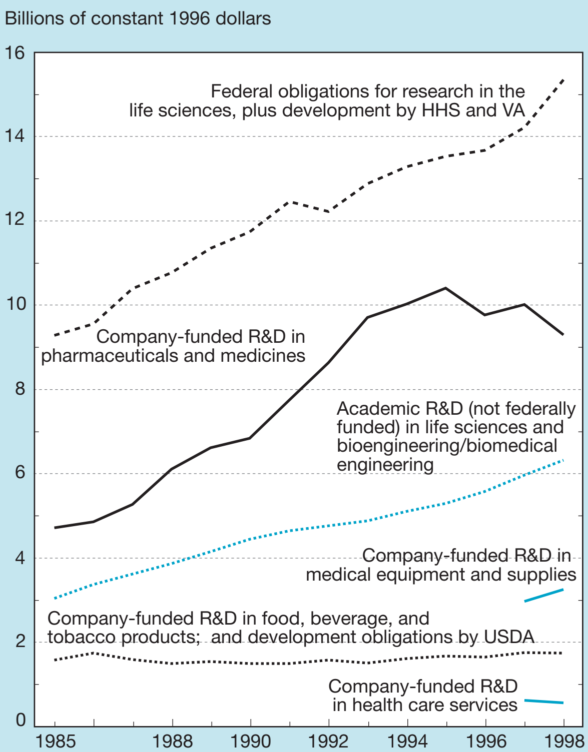
tures in this category grew from $6.6 billion in 1985 to $8.8 billion in 1998, although the sector has displayed considerable year-to-year fluctuation between 1996 and 1998 (inclusive). The next two categories were much smaller. Federal obligations for research in chemistry and chemical engineering declined between 1985 and 1998, from $1.2 to $980 million (in constant 1996 dollars). Academic R&D (not federally funded) in chemistry and chemical engineering, the smallest category, grew steadily in real terms, from $237 million in 1985 to $444 million in 1998.

R&D in Life Sciences. The broad life sciences field accounted for $36.5 billion of R&D in 1998 (in constant 1996 dollars). R&D in this area is characterized by strong and fairly continuous real growth in its three largest categories. (See figure 4-16.) The largest of these three, Federal obligations for research in the life sciences, plus development expenditures by HHS and the Department of Veterans Affairs, rose from $9.3 billion in 1985 to $15.4 billion in 1998 in constant 1996 dollars. Company-funded R&D in pharmaceuticals and medicines grew dramatically in real terms, from $4.7 billion in 1985 to $10.4 billion in 1995 but then declined to $9.3 billion by 1998. In contrast, academic R&D (not federally funded) in life sciences and bioengineering/biomedical engineering grew continuously, from $3.0 billion in 1985 to $6.3 billion in 1998.

Figure 4-16.
R&D associated primarily with life sciences



HHS = Department of Health and Human Services; USDA = U.S. Department of Agriculture; VA = Department of Veterans Affairs

See appendix table 4-29.

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With regard to food and other traditional products, however, company-funded R&D in food, beverage, and tobacco products, and development expenditures by USDA, show virtually no real R&D growth. That is, as shown in figure 4-16, R&D for this combined subcategory grew only from $1.6 to $1.7 billion between 1985 and 1998. Finally, two new categories of industrial R&D in the life sciences, arising from the new NAICS classification system, are company-funded R&D in health care services and company-funded R&D in medical equipment and supplies. In 1998, the former accounted for $566 million in R&D and the latter for $3.3 billion, in constant 1996 dollars.

Research Alliances: Trends in Industry, Government, and University Collaboration

All major players involved in the creation, diffusion, and commercialization of R&D have experienced changes in how innovation activities are financed, organized, and performed (Jankowski 2001a; Mowery 1998). Well-known risks of conducting scientific research and commercializing its results have been compounded by the increased speed and interdisciplinary nature of technological developments. In this environment, collaborations and alliances, at home or overseas, allow partners to share R&D costs, pool risks, and enjoy access to firm-specific know-how and commercialization resources (Hagerdoon, Link, and Vonortas 2000; Vonortas 1997). In the policy arena, changes in antitrust regulations, intellectual property policy, and technology transfer have fostered a new setting for collaborative research since the early 1980s. (See sidebar, “Major Federal Legislation Related to Cooperative R&D and Technology Transfer.”) These changes have paralleled policy and market trends in other advanced economies, contributing to a national and global economy increasingly dependent on knowledge-based competition and networking.

Joint research activities complement other tools to acquire or develop technology, from licensing off-the-shelf technologies to mergers and acquisitions (M&A). Corporate R&D planning increasingly requires a combination of technology exchange (acquisition of external R&D outputs as well as spinoff of noncore technologies) and strategic R&D alliances to excel in innovation and market performance (Arora, Fosfuri, and Gambardella 2000).[25] Even local and Federal Government agencies have developed technology strategies to maximize regional competitive advantage and national benefits. Universities also have adjusted to this new environment by increasing funding links, technology transfer, and collaborative research activities with industry and Federal agencies over the last two decades.

At the same time, collaborative networks are not without risks. Unintended transfer of proprietary technology is always a concern for businesses. Cultural differences among differ-

[25]M&A activity and international R&D investments are covered in a separate section below.

Major Federal Legislation Related to Cooperative R&D and Technology Transfer

- ♦ **Stevenson-Wydler Technology Innovation Act (1980)**—required Federal laboratories to facilitate the transfer of federally owned and originated technology to state and local governments and to the private sector.
- ♦ **Bayh-Dole University and Small Business Patent Act (1980)**—permitted government grantees and contractors to retain title to federally funded inventions and encouraged universities to license inventions to industry. The act is designed to foster interactions between academia and the business community.
- ♦ **Small Business Innovation Development Act (1982)**—established the Small Business Innovation Research (SBIR) program within the major Federal R&D agencies to increase government funding of research with commercialization potential within small, high-technology companies.
- ♦ **National Cooperative Research Act (1984)**—encouraged U.S. firms to collaborate on generic, precompetitive research by establishing a rule of reason for evaluating the antitrust implications of research joint ventures. The act was amended in 1993 by the National Cooperative Research and Production Act, which let companies collaborate on production as well as research activities.
- ♦ **Federal Technology Transfer Act (1986)**—amended the Stevenson-Wydler Technology Innovation Act to authorize cooperative research and development agreements (CRADAs) between Federal laboratories and other entities, including state agencies.
- ♦ **Omnibus Trade and Competitiveness Act (1988)**—established the Competitiveness Policy Council to develop recommendations for national strategies and specific policies to enhance industrial competitiveness. The act created the Advanced Technology Program and the Manufacturing Technology Centers within NIST to help U.S. companies become more competitive.
- ♦ **National Competitiveness Technology Transfer Act (1989)**—amended the Stevenson-Wydler Act to allow government-owned, contractor-operated laboratories to enter into cooperative R&D agreements.
- ♦ **National Cooperative Research and Production Act (1993)**—relaxed restrictions on cooperative production activities, enabling research joint venture participants to work together in the application of technologies they jointly acquire.
- ♦ **Technology Transfer Commercialization Act (2000)**—amended the Stevenson-Wydler Act and the Bayh-Dole Act to improve the ability of government agencies to license federally owned inventions.

ent industries, academic or government partners, or international collaborators present additional difficulties for managing alliances. On the other hand, the degree of cohesion among members may bring unintended anticompetitive behavior or may conflict with other economic or science policy objectives. For example, industry-university and industry-government collaborations have highlighted concerns about adequate availability of research findings in certain scientific areas.[26]

Types of Research Partnerships

Collaborations can be classified and analyzed according to several criteria. By type of members, there are a variety of business, university, and government combinations, including government-to-government technical collaborations. In terms of activities, business alliances may focus on manufacturing, services, marketing, or technology-based objectives. For example, according to an OECD paper, R&D alliances represent as many as 23 percent of all types of alliances in North America compared with 14 percent in Western Europe and 12 percent in Asia (Kang and Sakai 2000). Also according to this study, North America is the only region in which the share of R&D alliances is higher than the share of manufacturing alliances.

Technology-based collaboration broadly defined includes joint research activities, technology codevelopment, contract research, and technology exchange (licensing and cross-licensing). In particular, strategic research partnerships (SRPs), a subset of these broad interactions, emphasize joint R&D activities as opposed to contract research or other exclusively financing or exchange transactions. SRPs can take the form of formal joint ventures (a specific term in many legal codes internationally) or more informal agreements. Types of SRPs found in available databases and published studies include research joint ventures (RJVs), cooperative R&D agreements, and strategic technology alliances.

According to Hagerdoon, Link, and Vonortas (2000), in the early 1970s the majority of research partnerships were equity-based research corporations, but "[b]y the mid-1990s, more than 85 percent of research partnerships did not involve equity investments." This is attributed in large part to the higher degree of organizational flexibility of nonequity agreements. Still, SRPs of any type constitute a highly flexible tool for pursuing new technology venues. A relatively small participation in any one alliance may bring the full benefits of the research outputs, which may be further developed or commercialized. Furthermore, these partnerships may evolve into other types of agreements or acquisitions, or they may serve as an entry into new geographic markets over time.

Dedicated databases tracking these developments and sponsored in part by NSF include the Cooperative Research (CORE) database, the National Cooperative Research Act (NCRA)-RJV database, and the Cooperative Agreements and Technology Indicators database compiled by the Maastricht

[26]For an overview of the issues, see Behrens and Gray (2001); Feldman et al. (2001); Brooks and Randazzese (1998); and Cohen et al. (1998).

Economic Research Institute on Innovation and Technology (CATI-MERIT) (Link and Vonortas 2001). The first two cover U.S.-based alliances recorded in the *Federal Register,* pursuant to the provisions of NCRA.[27] Trends in either database are illustrative only of the technical and organizational characteristics of joint ventures in the United States because the registry is not intended to be a comprehensive count of cooperative activity by U.S.-based firms. The CATI-MERIT database covers international collaborations based on announcements of alliances and tabulated according to the country of ownership of the parent companies involved.[28]

Domestic Public and Private Collaborations, Including Federal Programs

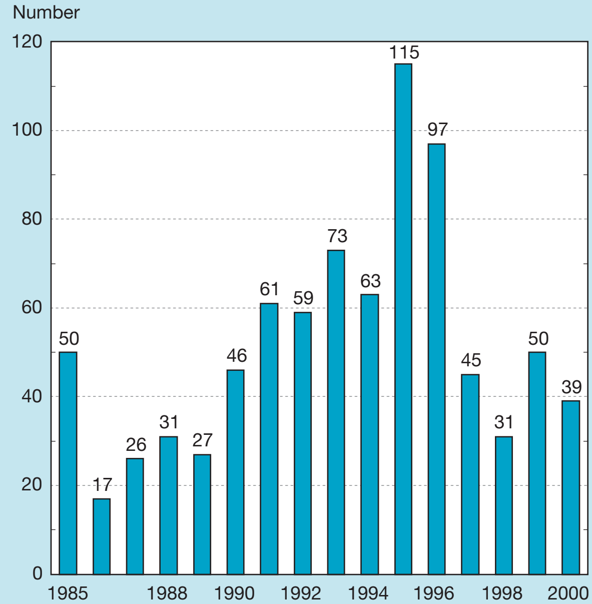
Research Joint Ventures

More than 800 RJVs were registered in the NCRA-RJV database from 1985–2000.[29] According to Vonortas (2001), from 1985 to 1999 these collaborations involved more than 4,200 unique businesses and organizations. Of these participating organizations, more than 3,000 (about three-fourths) were U.S. based; 88 percent of these domestic participants were for-profit firms, 9 percent were nonprofit institutions (including universities), and 3 percent were government units. Two-thirds of the organizations represented in these alliances participated in only one collaboration over the 15-year period ending in 1999; another 27 percent participated in two to five alliances.

The CORE database (Link 2001), based on collaborations as a unit, shows the following trends:

- In 2000, there were 39 new RJVs compared with 50 in 1999. New filings peaked in 1995 at 115 after increasing successively since 1986. (See figure 4-17.) Brod and Link (2001) estimated a statistical model to explain the trends in RJVs filings, including the decline since the 1995 peak. They find that filings are likely to be countercyclical. In particular, they argue that "[w]hen the economy is strong and…R&D is growing, firms may rely less on cooperative research arrangements…than when the economy is weak and internal resources are more constrained."
- Half of the research joint ventures in 1985–2000 involved companies in three industries: electronic and electrical equipment (148 of 829, or 18 percent), communications (135, or 16 percent), and transportation equipment (127, or 15 percent).

Figure 4-17.
Domestic research joint ventures: 1985–2000



NOTE: Data are annual counts of new research joint ventures registered under the National Cooperative Research and Production Act.

SOURCE: Based on data from Link, A. 2001. *Federal Register Filings: The 2000 Update of the CORE Database.* Report submitted to the National Science Foundation, Arlington, VA.

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In terms of the composition of these joint ventures, petroleum refining (SIC 29) and related oil and gas extraction each had a median of eight members, the highest among individual industries over 1989–99. Chemicals (SIC 28) and electronic and electrical equipment and components (SIC 36) had a median of six and five, respectively.[30] Participation of universities and Federal agencies in these colaborative activities is discussed next.

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[27]Domestic data come from *Federal Register* filings of RJVs. Restrictions on multifirm cooperative research relationships were loosened by NCRA in 1984 (Public Law 98-462) after concerns over the technological leadership and international competitiveness of American firms in the early 1980s. This law was enacted to encourage U.S. firms to collaborate on generic, precompetitive research. However, to gain protection from antitrust litigation, NCRA requires firms engaging in RJVs to register them with the Department of Justice. In 1993, the National Cooperative Research and Production Act (NCRPA, Public Law 103-42) extended legal protection to collaborative production activities.

[28]The CATI database is compiled by the Maastricht Economic Research Institute on Innovation and Technology in the Netherlands. The data consist of thousands of interfirm cooperative agreements. These counts are restricted to strategic technology alliances, such as joint ventures for which R&D or technology sharing is a major objective, research corporations, and joint R&D pacts. CATI is a literature-based database. Its key sources are newspapers, journal articles, books, and specialized journals that report on business events. Because data are limited to activities publicized by the firm, agreements involving small firms and certain technology fields are likely to be underrepresented. Another limitation is that the database draws primarily from English-language materials.

[29]Note that data from the *Federal Register,* while illustrative, are based on a specific legislative intent focused on antitrust concerns, as opposed to a dedicated survey activity. This fact may bias the RJVs counts and/or their composition in several ways. In one respect, the counts may fall short of the true extent of the phenomenon depending on the (perceived) antitrust climate over time. On the other hand, some joint ventures may register an excessive number of members, even if actual research activity is limited to few R&D active partners.

[30]In some SICs, the average number of members is inflated by several consortia with as many as several hundred members. These large groupings may not represent actual collaborative research activity but agreements to share results by providing funding, facilities, or other type of support, while joining a legally sanctioned umbrella. In particular, there are at least 19 consortia with more than 100 members in this database, many of which have multiple university members, as well as government participation.

Public-Private Collaborations

Collaborative S&T activities may involve public institutions, such as government agencies and universities, as well as other nonprofit research organizations. Activities include transfer of technology from Federal laboratories and universities, small business S&T programs, and the Advanced Technology Program. See sidebar, "The Advanced Technology Program: 1990–2000 Trends."

Federal Technology Transfer Programs. In general, technology transfer can be defined as the exchange or sharing of technology or technical knowledge across different organizations. It can take place in a number of scenarios: in public or private research collaborations (the focus of this section), in fee-based transactions (licensing and trade), and in training or hiring activities. The role of Federal agencies and laboratories, either as a source of technology to be commercialized by private parties or as a research partner, is considerable given substantial Federal R&D activity, as described earlier in the chapter. Public policy objectives for Federal cooperative research and technology transfer activities include the support of mission objectives such as defense, public health, and the promotion of competitiveness and economic growth (Bozeman 2000). One common technology transfer mechanism is a license that confers rights to exploit commercially a patented or otherwise proprietary technology. Other technology transfer mechanisms include cooperative agreements, personnel exchange, user facility agreements, and technical assistance.

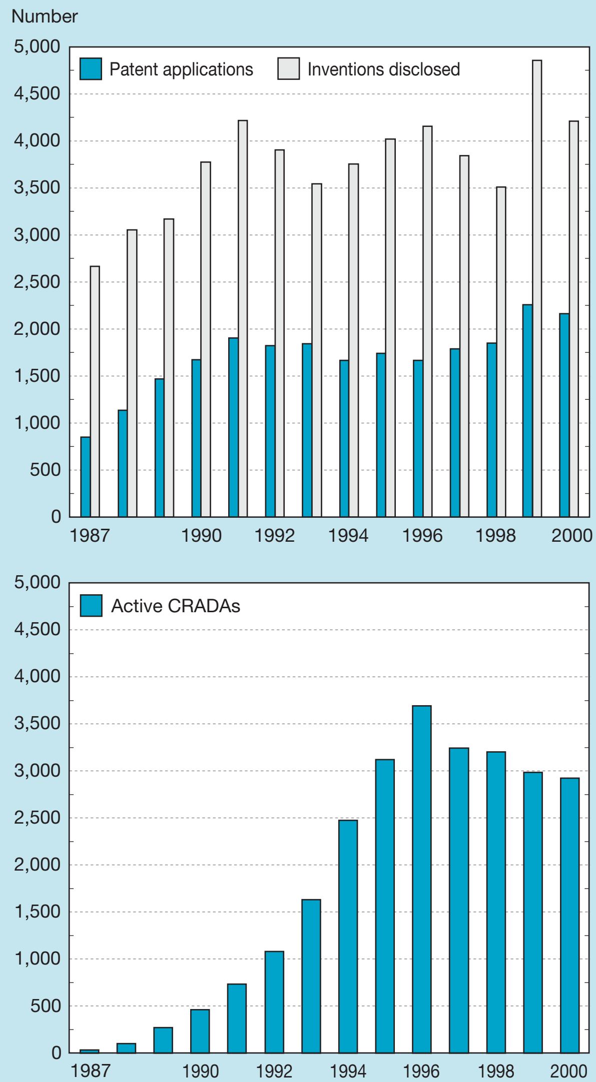
In the early 1980s, Federal technology transfer became widely regarded as a means of addressing Federal concerns about U.S. industrial strength and world competitiveness. The Stevenson-Wydler Technology Innovation Act of 1980 added technology transfer of Federally-owned or originated technology as an explicit mission of Federal laboratories. In the same year, the Bayle-Dole Act specified the authority of Federal agencies to obtain patents, grant licenses, and transfer custody of patents with the explicit purpose of promoting the utilization and marketing of inventions under Federally-funded R&D by nonprofit organizations and small businesses. Subsequent amendments repealed the restriction to grant an exclusive license only to small firms (Schacht 2000). Later in the decade, the Federal Technology Transfer Act of 1986 authorized government-owned and government-operated laboratories to enter into Cooperative Research and Development Agreements (CRADAs)[31] with private industry and gave all companies, regardless of size, the right to retain title to inventions (Schacht 2000). The 1989 passage of the National Competitiveness Technology Transfer Act extended this authority to contractor-operated labs (including DOE's FFRDCs). More recently, the Technology Transfer Commercialization Act of 2000 (Public Law 106-404) improved the ability of Federal agencies to license federally owned inventions.

[31]The statute defines CRADAs as any agreement between one or more laboratories and one or more non-Federal parties in which the government shares personnel, facilities, equipment, or other resources (but not funding) with non-Federal parties for the purpose of advancing R&D efforts consistent with the missions of the laboratories.

Data on technology transfer activities from Federal agencies are reported to the Department of Commerce and include inventions disclosed, Federally-owned patents, licenses of patented inventions, income from those patented inventions, and the number of CRADAs. In 2000, Federal agencies involved in R&D and technology transfer activities reported 4,209 invention disclosures, 2,159 patent applications, and 1,486 patents issued. (See figure 4-18 and appendix table 4-35.) Since fiscal year 1997, a total of 5,655 patents have been issued to Federal agencies.

A total of 2,924 CRADAs involving 10 Federal agencies and their laboratories were active in 2000. The largest participants by far are DOD laboratories (1,364 active CRADAS or 47 percent of the total) and DOE (687 or 23 percent). The number of active CRADAs increased rapidly in the early and

Figure 4-18.
Federal technology transfer indicators: 1987–2000



CRADA = Cooperative Research and Development Agreement

See appendix table 4-35.

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The Advanced Technology Program: 1990–2000 Trends

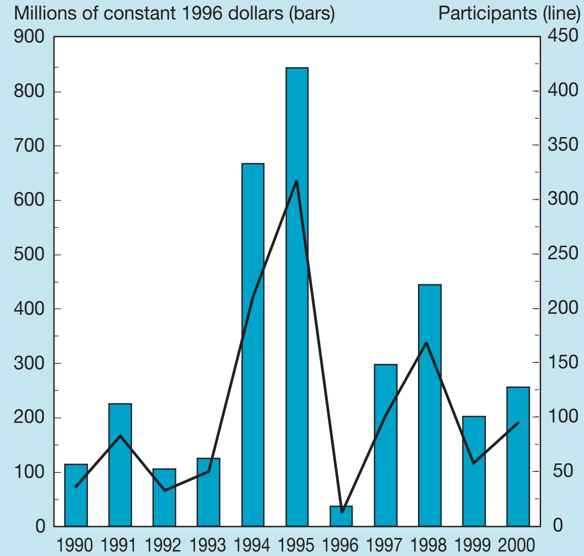
The Advanced Technology Program (ATP), National Institute of Standards and Technology, U.S. Department of Commerce, has funded the development of high-risk enabling technologies since 1990. Proposals are submitted to a peer review process based on technical and economic criteria. Awards are made on a cost-share basis for both single applicants and joint ventures.

During the 1990–2000 period, over 1,100 companies, nonprofit institutions, and universities participating in the program received $3.3 billion in R&D funding—divided about equally between ATP and industry funds. (See appendix table 4-38.) These participants pursued 522 projects in five technology areas: biotechnology, electronics, information technology, advanced materials and chemistry, and manufacturing. In terms of project structure, 350 projects (67 percent) were single-company projects and 172 (33 percent) were joint ventures; 812 participants (70 percent) were members of joint ventures over this 11-year period.

In 2000, funding for projects increased 27 percent to $256 million in constant 1996 dollars after declining more than 50 percent in 1999. (See figure 4-19.) The funding in 2000 included $135 million (53 percent) from ATP and $122 million (47 percent) from industry. At the same time, the number of awards increased 46 percent to 54, whereas the number of participants increased by 67 percent. Funding for the ATP program peaked in the last two years of the first Clinton administration, declined drastically in 1996, and has ranged between one-fourth and one-third of the 1995 peak ever since.

The ups and downs in ATP funding over the 1990s reflect, in part, an ongoing debate over the program's goals. On one hand, the inherent technical and market risks and the inability of private firms to fully capture the benefits in some enabling technologies are recognized by most observers as generating underinvestment

Figure 4-19.
ATP funding and number of participants: 1990–2000



ATP = Advanced Technology Program

NOTE: Constant dollars based on fiscal year GDP implicit price deflators (appendix table 4-1).

See appendix table 4-38.

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in certain R&D areas. However, the role and effectiveness of ATP and similar technology partnership programs as policy tools to answer this challenge are still under debate.* At the time of this writing, the Bush administration's FY 2002 budget calls for the suspension of new awards and for an evaluation of the program to assess long-term funding (U.S. OMB 2001b).

*For empirical studies related to this debate see David, Hall, and Toole (2000). For public policy analysis of the program, see Wessner (2001) and references therein.

mid-1990s, reached a peak of 3,688 in fiscal year 1996, and stabilized around 3,000 since. (See figure 4-18.) For a comprehensive review of licensing and other policy issues in CRADAS using data on the above indicators to fiscal year 1998, see U.S. OTP (2000). Other data on CRADAs such as internal structure (membership profiles, organizational structure), activities, and research outputs (licensing, commercial and agency mission impacts) have been explored by a number of case studies but are unavailable from more comprehensive survey data.[32]

Industry-University Collaboration. Even though the Federal Government still provides the bulk of university research funding, universities have adjusted to the decreasing role of the Federal Government in R&D funding by relying increasingly on non-federal funding sources[33] and by engaging in collaborations with nonacademic organizations (Jankowski 1999). Universities have also increased their patenting and technology transfer activities, notably since the Bayh-Dole Act of 1980 (and subsequent amendments) allowed them to patent federally funded research (Mowery et al. 2001; Nelson 2001).[34] From the perspective of industry, joint research activities with academia support industrial research objectives and comple-

[32]See Mowery, David, C. *Using Cooperative Research and Development Agreements as S&T Indicators: What Do We Have and What Would We Like?* in NSF (2001g) and references therein.

[33]For a discussion of funding of academic R&D in the U.S. and other advanced economies, see "International Comparisons of National R&D Trends" later in the chapter.

[34] For more on university patenting activity and technology transfer see 'Outputs of Scientific and Engineering Research' in Chapter 5, Academic Research and Development, of this volume. See also the special issue of the *Journal of Technology Transfer* on the Symposium on University-Industry Technology Transfer (vol. 26, no. 5, January 2001).

ment other aspects of industry-university relations, including most notably the hiring of graduates.

Federal assistance for cooperative research centers between industry and academia, including NSF's Cooperative Research Centers, was specified in the Federal Technology Transfer Act of 1986.[35] A paper based on a survey of NSF's Industry-University Cooperative Research Centers (IUCRCs) suggests that these centers have had a positive impact on joint authorship with university scientists, contract research, licensing of university patenting, and hiring of graduate studies (Adams, Chiang, and Starkey 2001).

The CORE database on research alliances (described earlier) provides some indication of the extent of these public-private collaborations. For the 1985–2000 period, universities participated in 15 percent of these RJVs, and 11 percent had at least one Federal laboratory member. However, eight percent of domestic alliances had at least one university as a research member in 2000, down from 16 percent in 1999 and below the 30 percent peak in 1996.

From 1985–2000, 30 percent of RJVs in electronic and electrical equipment (SIC 36) and 19 percent of industrial machinery RJVs (including computer manufacturing) had at least one U.S. university as a partner, topping all industries in this category (see figure 4-20). Collaborations in these two industries also had the highest level of participation by Federal laboratories.

Small Business S&T Programs. Small businesses have a long-recognized role in fostering local and national economic growth. In the S&T arena, this recognition translates into the effort to increase the participation of small business in Federal R&D and technology transfer. Although economic activity and R&D performance tend to be performed by large firms in the manufacturing sector and small firms in the nonmanufacturing sector, as discussed earlier in the chapter, economists have debated over the years whether smaller or larger firms are more likely to engage or succeed in innovative activities. Further studies have shown that their relative incentives and efficiencies in research and commercialization depend on a number of institutional and technological characteristics over the life cycle of products or industries. Furthermore, alliances between small or startup firms and established companies may fare better than either type of business individually.

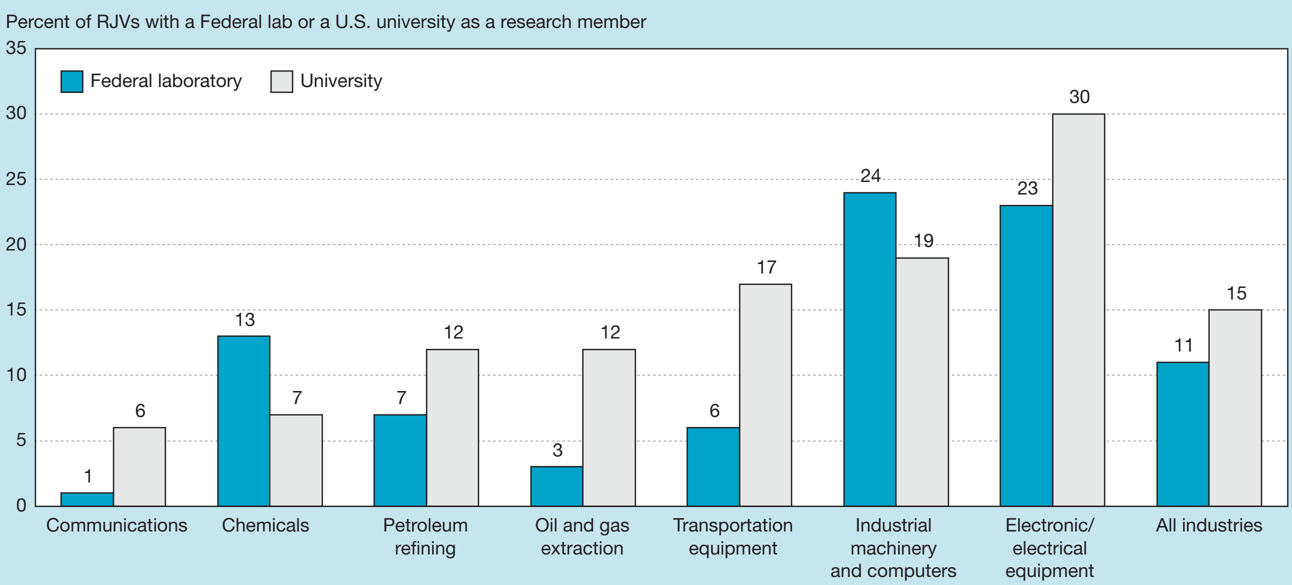
Nevertheless, smaller firms are more likely than larger or more established companies to be affected by a number of financing and other market constraints. Internal funds have been shown to significantly affect R&D activity conducted by small high-technology firms.[36] Larger firms may be able to produce cash flows above investment needs and generally have better access to capital markets. Smaller or younger firms in high-technology sectors have the additional burden of being engaged in riskier technological activities with unproved market records.

SBIR. The Small Business Administration (SBA) has a key role helping small and disadvantaged firms obtain financing, government R&D contracts, or technology transfer opportu-

[35]Sections 3705, 3706, and 3707 of Title 15, United States Code.

[36]In particular, R&D has a stronger relationship with the permanent or long-term component of cash flows. For example, permanent funding is required for R&D personnel, who are costly to hire and train (Himmelberg and Petersen 1994).

Figure 4-20.
Participation of public organizations in industry RJVs: 1985–2000



RJVs = research joint ventures

SOURCE: Based on data from Link, A. 2001. *Federal Register Filings: The 2000 Update of the CORE Database.* Report submitted to the National Science Foundation, Arlington, VA.

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nities, and providing technical support for R&D and commercialization activities.[37] A major tool of this policy objective is the Small Business Innovation Research (SBIR) program, created by the Small Business Innovation Development Act of 1982 (Public Law 97-219), coordinated by SBA. Ten years into the program, it was reauthorized with an emphasis on commercialization "as an explicit criterion when evaluating proposals" (Public Law 102-564).[38] The same bill created the Small Business Technology Transfer (STTR) program, a smaller program emphasizing cooperative R&D and technology transfer.[39]

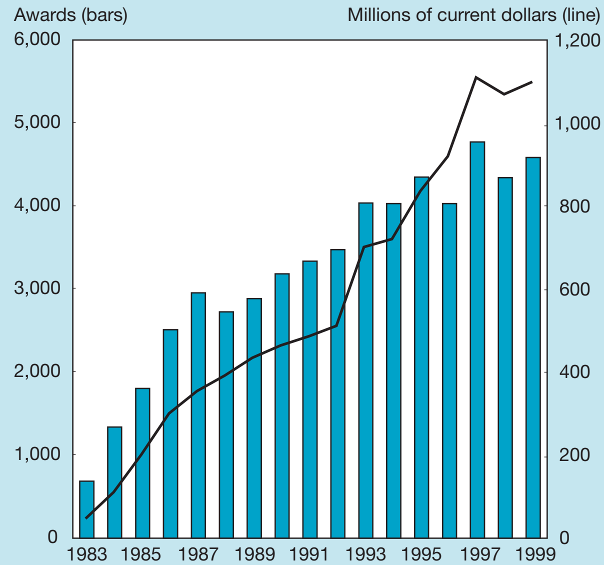
The programs do not represent separate funding from SBA but, rather, redirect other Federal agencies' R&D funds to small firms (those with 500 or fewer employees). Projects are administered by participating agencies. Specifically, Federal agencies with extramural R&D obligations above $100 million must set aside a fixed percentage of such obligations for SBIR projects. This set-aside has been at 2.5 percent since FY 1997. To obtain this Federal funding, a company applies for a Phase I SBIR grant. The proposed project must meet an agency's research needs and have commercial potential. If approved, grants of up to $100,000 are made. If the concept shows further potential, the company can receive a Phase II grant of up to $750,000. In Phase III, the innovation must be brought to market with private-sector investment and support; no SBIR funds may be used for Phase III activities.

From 1983 to 1999, SBIR awarded $9.7 billion to over 55,000 projects. Projects included research in computers, information processing and electronics, materials, energy, environmental protection, and life sciences. In 1999, the program awarded $1.1 billion in R&D money to 4,590 projects. (See figure 4-21.) Ten agencies participated in FY 1999; DOD is the largest participant with $514 million (47 percent), followed by HHS with $314 million (29 percent), funding 1,962 (43 percent) and 1,236 (27 percent) projects, respectively, in 1999. (See appendix table 4-36.) Given the design of the program, its overall size and agency participation mirror the size and composition of the Federal extramural R&D budget.

On average, approximately three-fourths of the awards are for Phase I, but they use only about 30 percent of the funds. There are many more projects in the first exploratory phase because only the most worthy projects (in terms of technical and commercialization prospects) move to the second phase. At the same time, these second-phase projects have used an increasing share of the funds from all agencies combined. This reflects an increase in dollars per Phase II project from the low $300,000s at the beginning of the program to $635,000 in 1999.[40]

The geographic distribution of SBIR awards reflects the overall concentration of total Federal R&D funding. In particular, in FY 1998, the top five states (California, Massachusetts, Virginia, Maryland, and Colorado) received one-half of both awards and SBIR dollars. Several agencies have used the SBIR program in conjunction with other outreach programs to increase participation of states with traditionally low levels of Federal R&D funding. For example, according to the U.S. GAO (1999b) report, NSF has used its Experimental Program to Stimulate Competitive Research (EPSCoR) to increase assistance to SBIR participants in EPSCoR states and the Commonwealth of Puerto Rico.[41] Assistance includes a "Phase Zero" award to help in the preparation of SBIR proposals.

Figure 4-21.
Growth in SBIR awards and funding: 1983–99



SBIR = Small Business Innovation Research

See appendix table 4-36. *Science & Engineering Indicators – 2002*

STTR. The STTR program pairs eligible small businesses with either nonprofit institutions or an FFRDC to perform joint R&D projects. The purpose is to leverage the technical resources of these research institutions (mostly universities) with small businesses for technology development, transfer, and commercialization. Participating small businesses must perform at least 40 percent of the work and be in overall control of the project. The program is structured, much like the SBIR program, in three phases. The first phase studies technical and commercial feasibility with funding not to exceed $100,000 for one year; further development occurs in the second phase with a maximum of $500,000 in funds over two years. In the last phase, the participants engage in commercial applications with no Federal STTR funds.

Five Federal agencies with more than $1 billion in extramu-

[37]See text of Public Law 106-554, December 2000. For analysis of small business research programs as public venture capital programs, see Lerner and Kegler (2000) and references therein.

[38]See also U.S. GAO (1999a).

[39]SBIR was reauthorized in December 2000 by the Small Business Reauthorization Act of 2000 (Public Law 106-554) through FY 2008 (September 30, 2008). A bill to reauthorize the STTR program, scheduled to expire in September 2001, was introduced in the Senate in May 2001 and placed on the Senate Legislative Calendar in late August 2001 (S. 856, 107th Congress).

[40]The average dollar amount per project is $61,800 for Phase I and $434,370 for Phase II over the life of the program through FY 1999.

[41]The states are Alabama, Arkansas, Idaho, Kansas, Kentucky, Louisiana, Maine, Mississippi, Montana, Nebraska, Nevada, North Dakota, Oklahoma, South Carolina, South Dakota, Vermont, West Virginia, and Wyoming.

ral R&D participate in the program: DOD, NSF, DOE, NASA, and HHS. Since FY 1996, the required set-aside has been 0.15 percent compared with 2.5 percent for the SBIR program.[42] From FY 1994 to FY 1999, the STTR program has awarded more than $300 million to more than 1,700 projects. In 1999, STTR awarded $65 million to 329 projects. (See appendix table 4-37.) Three-fourths of the projects were in Phase I. The largest participant by far is DOD. The majority of the research institutions participating were universities (283 of 329, or 86 percent). The remainder were divided between FFRDCs (22) and hospitals and other nonprofit organizations (24).[43]

International Private and Public Collaborations

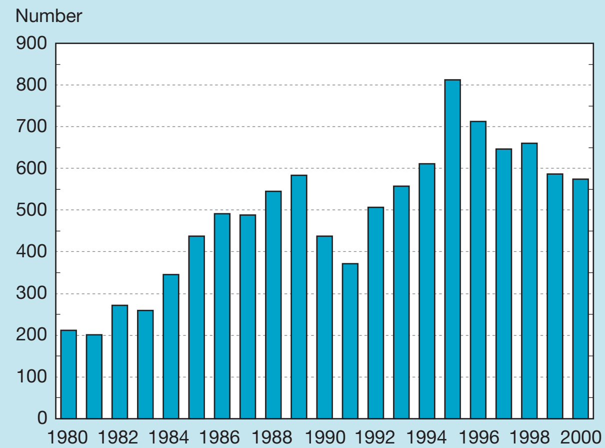
International Business Alliances

In 2000, 574 new technology or research alliances were formed worldwide in six major sectors: information technology (IT), biotechnology, advanced materials, aerospace and defense, automotive, and (nonbiotech) chemicals, according to the data available from MERIT-CATI (Hagerdoon 2001). Over the past two decades, the formation of international technology alliances has grown considerably. In particular, there were 6,477 technology alliances formed between 1990 and 2000 compared with 3,826 over 1980–89. However, international alliances peaked at 812 in 1995, the same year, domestic collaborations peaked in the CORE database. This is not surprising given the significant role of alliances involving U.S. companies. (See figure 4-22.)

The majority of the alliances involved companies from the United States, Japan, and countries of Western Europe. Fully 80 percent (5,187) of the 1990–2000 alliances involved at least one U.S.-owned company (see text table 4-12), compared with 64 percent in the 1980s. At the same time, European firms participated in 2,784 technology alliances. Japanese companies were involved in 910 partnerships, down slightly from the earlier period.[44] The dominance of U.S. companies in this database is also clear by noting that among the alliances involving at least one U.S. company, the share of alliances involving *only* U.S. firms increased from 37 percent in the 1980s to more than 50 percent in 1990–2000. (See figure 4-23.) On the other hand, European and Japanese companies engaged in more interregional collaborations compared with U.S. companies. As discussed below, these geographic patterns were driven by IT and biotechnology R&D activity.

Technology Focus. The share of biotechnology partnerships reached an all-time high of 35 percent in 2000 (199 of 574), continuing an increasing trend that began in 1991. (See figure 4-24.) Furthermore, this is the first time that biotech alliances have outnumbered IT partnerships in any given year in the database, dating back to the 1960s. In 2000, there were 184 (32

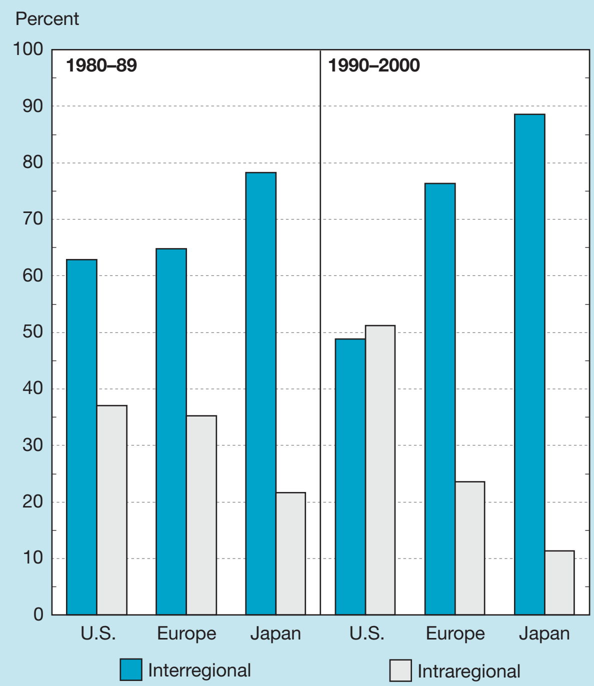
Figure 4-22.
International strategic technology alliances: 1980–2000



NOTE: Data are annual counts of new international strategic technology alliances.

See appendix table 4-39. *Science & Engineering Indicators – 2002*

Figure 4-23.
Shares of international strategic technology alliances: 1980–89 and 1990–2000



NOTES: Interregional share refers to the share of alliances formed by companies from different countries or regions. Intraregional shares consider only alliances among companies from the same country or region. Total alliances: 1980–89: U.S. = 2,445; Europe = 1,904; Japan = 1,073. 1990–2000: U.S. = 5,187; Europe = 2,784; Japan = 910.

See text table 4-12 and appendix table 4-39.

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[42]The initial set-aside percentages were 0.05 percent in FY 1994 and 0.1 percent in FY 1995.

[43]For a survey of companies receiving STTR awards see U.S. GAO (2001b and 2001c).

[44]As discussed previously, technology partnerships announced in non-English publications, such as those based in Asia, are likely to be undercounted.

Text table 4-12.
International strategic technology alliances: 1990–2000

Region	All alliances	Information technology	Biotechnology	All other technologies
		Counts		
All regions	6,477	2,687	1,553	2,237
USA-Europe	1,654	536	525	593
USA-Japan	511	292	82	137
USA-Others	364	158	71	135
Europe-Japan	239	92	37	110
Europe-Others	234	64	49	121
Japan-Others	56	30	6	20
Intra-USA	2,658	1,299	629	730
Intra-Europe	657	169	147	341
Intra-Japan	104	47	7	50
		Regional shares (percentages)		
All regions	100	100	100	100
USA-Europe	26	20	34	27
USA-Japan	8	11	5	6
USA-Others	6	6	5	6
Europe-Japan	4	3	2	5
Europe-Others	4	2	3	5
Japan-Others	1	1	0	1
Intra-USA	41	48	41	33
Intra-Europe	10	6	9	15
Intra-Japan	2	2	0	2
		Technology shares (percentages)		
All regions	100	41	24	35
USA-Europe	100	32	32	36
USA-Japan	100	57	16	27
USA-Others	100	43	20	37
Europe-Japan	100	38	15	46
Europe-Others	100	27	21	52
Japan-Others	100	54	11	36
Intra-USA	100	49	24	27
Intra-Europe	100	26	22	52
Intra-Japan	100	45	7	48

SOURCE: Based on data from the Cooperative Agreements and Technology Indicators (CATI) database, Maastricht Economic Research Institute on Innovation and Technology (MERIT), Maastricht, the Netherlands.

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percent) new IT partnerships, less than the 225 partnerships in 1999. The number of new IT alliances peaked in 1995 at 338, reaching a maximum share of 55 percent in 1991. More important, the combined shares of these two technologies increased from 55 percent in the 1980s to 66 percent in the 1990s.

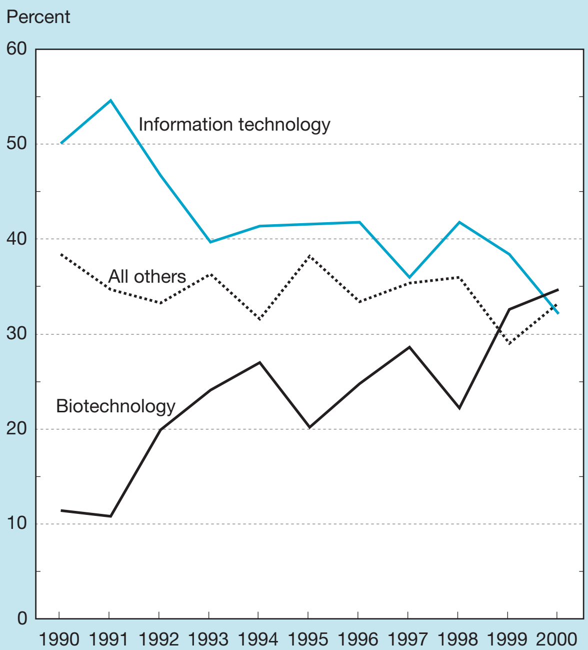
The United States and Europe were prime locales for biotechnology alliances during the 1990s, attracting the interest of venture capital and stimulating high-profile projects such as the decade-long effort to map the human genome. Of the 1,500 biotechnology alliances in the past decade, 41 percent involved U.S. companies only and another 34 percent involved pairings of U.S. and European companies (see text table 4-12). This partnering is likely to intensify in coming years as biotechnology startups and pharmaceutical firms collaborate with instrument, software, and bioinformatic companies for the next research step dubbed “proteomics,” which involves mapping the structure and function of proteins based on gene expression databases (Hamilton and Regaldo 2001).

Interregional IT alliances have become less frequent in the MERIT-CATI database. In 1990–2000, a majority of IT partnerships (56 percent) were within countries or regions (United States, Japan, or the European region), as opposed to alliances across regions (44 percent). This compares with an even split between these two types of IT alliances in the 1980s. Furthermore, U.S.-only partnerships represent about one-half of IT alliances, up from 29 percent in the 1980s.

Government-to-Government Cooperation

Nation-to-nation cooperation constitutes a special case of international research collaboration. In addition to the rationale for collaborative projects discussed earlier, these projects often have an added dimension in terms of foreign policy objectives and security issues. Some so-called megaprojects are characterized by extremely high costs, key national stakes, and often multiple international stakeholders. Forms of international government collaboration include

Figure 4-24.
International strategic technology alliances, by technology shares



See appendix table 4-39.

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joint construction, operation, and use of large facilities for research or exploration (e.g., space and nuclear physics) and joint research activities.[45]

At least three organizational forms of government-to-government S&T collaboration can be identified. An individual U.S. agency may collaborate with sister agencies abroad to pursue common R&D interests, leveraging funds and technical expertise. U.S. agencies may also form a research umbrella to work together among themselves and then engage in joint activities with overseas organizations as needed. Governments also may use international organizations to advance scientific or technical objectives, often in conjunction with complementary national goals. See sidebar, “Collaborative R&D Projects in Selected International Organizations.”

Looking at agency-specific activities, the U.S. GAO (1999b) estimated that 575 international S&T agreements existed between seven U.S. agencies (DOE, NASA, NIH, NIST, NSF, National Oceanic and Atmospheric Administration (NOAA), and the State Department) and other countries in FY 1997. However, not all of these S&T agreements included cooperative R&D activities. At the same time, cooperative R&D projects also occur outside such formal international interagency agreements. Funding data are particularly scarce. A report by RAND’s Science and Technol-

[45]Projects in this category can cost as much as several billion U.S. dollars over many years of planning and development. See Boesman (1994) and U.S. Congress, Office of Technology Assessment (1995).

Collaborative R&D Projects in Selected International Organizations

In addition to national agencies, governments also use international organizations to promote, study, and coordinate scientific collaboration. The following is a sample of scientific activities coordinated by international organizations.

- **Global Forum on Agricultural Research.** The activities of the Global Forum on Agricultural Research (GFAR) include the promotion of research partnerships in agricultural R&D as well as the exchange of scientific and technical information. GFAR is fostering global and regional research partnerships in the areas of biotechnology, plant genetics, biodiversity, agroecology, and natural resources management (website: <http://www.egfar.org/>).
- **North Atlantic Treaty Organisation (NATO) Science Program—Cooperative Science and Technology Program.** This program supports conferences, workshops, and collaborative grants for scientists of NATO and some partner countries. Four scientific areas are covered: life sciences, physics and engineering, environmental and earth sciences, and security-related civil S&T (website: <http://www.nato.int/science/e/cst.htm>).
- **Organisation for Economic Co-operation and Development (OECD) Global Science Forum.** The OECD’s Global Science Forum identifies opportunities for international cooperation in basic scientific research. The forum establishes special- purpose working groups and workshops to perform technical analyses. Activities include workshops on structural genomics, compact ultrahigh-power lasers, a consultative group on high-energy physics, a working group on neuroinformatics, and a task force on radio astronomy and the radio spectrum (website: <http://www.oecd.org >).
- **World Health Organization’s Special Program for Research and Training in Tropical Diseases.** The World Health Organization’s (WHO’s) Special Program for Research and Training in Tropical Diseases was established in 1975 and is cosponsored by the United Nations Development Program, the World Bank, and WHO. The program supports global efforts to combat a portfolio of major diseases affecting developing countries (website: <http://www.who.int/tdr/about/mission.htm>).

ogy Policy Institute tries to fill this gap by compiling R&D spending data on international cooperative projects sponsored by U.S. agencies (Wagner, Yezril, and Hassell 2001).

The RAND report finds that approximately $4.4 billion in R&D spending by Federal agencies involved a significant international content in FY 1997 compared with $70 billion in total Federal obligations for R&D work in that year. The vast majority of the spending involves scientist-to-scientist collaboration in joint research projects. Technical support to aid a foreign country was a distant second. The largest spending for binational R&D cooperation was identified in projects involving Russia, Canada, the United Kingdom, Germany, and Japan. Spending in collaborative R&D with Russia increased considerably since the dissolution of the Soviet Union, especially in aerospace and aeronautics. Other scientific and policy interests in this area of the world include containing nuclear materials and aiding the transition of Russian scientists from weapons to civilian research.

Spending in aerospace and aeronautics accounted for more than one-half of the U.S. R&D dollars committed to a single field of collaboration across all countries. Biomedical and other life sciences, engineering, and energy fields also received significant international support. In part, the preeminence of aerospace research in international research spending is due to the disproportionate share of NASA in these statistics, fully $3.1 billion of the reported $4.4 billion, including funding for large multicountry projects such as the International Space Station and the Earth Observing Satellite System. Undoubtedly, international R&D support provided by other agencies is somewhat undercounted. For example, DOD figures reported at $263 million are likely to be an underestimate due to data validation problems, according to RAND. NIH, NSF, and DOE also perform key international work with projects in human genetics, infectious diseases, geosciences, and other basic research and energy sciences.

In another approach, U.S. agencies have formed interagency research groups that subsequently pursue international activities. For example, the U.S. Global Change Research Program (USGCRP), in place since 1989, studies climate change and Earth ecosystems and performs some of its research and data gathering on an international basis.[46] The program authorized research funds of $758 million in FY 2000 from NASA, NSF, DOE, NOAA, USDA, and other agencies (Executive Office of the President 2001). Another $937 million was authorized in support of NASA's development of Earth-observing satellites and related data systems as part of USGCRP activities. (For a summary of recent efforts to more fully integrate the use of collaborative activities in the international S&E arena, see sidebar, "The NSB Task Force on International Issues in Science and Engineering.")

[46]For a description of international activities of the program, see <http://www.usgcrp.gov/usgcrp/links/relintpr.html>.

The NSB Task Force on International Issues in Science and Engineering

The National Science Board (NSB) is responsible for monitoring the health of the national research and education enterprise. In recent years, the importance of science and technology in the global context has grown. As a result, both private sector and government cooperation in international science and engineering have become more prominent.

The NSB took note of these developments in preparing its strategic plan (NSB-98-215), in which it observed that one of the most important challenges confronting the United States is how to deal with science and engineering in the global context. The National Science Board expressed the need for a fresh assessment of the roles and needs of science and engineering in the international arena, and for a coherent strategy that supports a productive relationship between scientific and foreign policy objectives.

The Board subsequently established the Task Force on International Issues in Science and Engineering to undertake this assessment. The task force was charged with examining the Federal policy role and the institutional framework that supports international cooperation in research and education, as well as NSF's leadership role in international S&E in the 21st century. The task force has organized symposia, workshops, and panel discussions with a broad array of experts and stakeholders and has conducted an extensive review of relevant policy documents and reports. Two interim reports will be followed shortly by a comprehensive National Science Board report on international science and engineering.

Further information about the work of the task force can be found on the Board's website at <http://www.nsf.gov/nsb/>.

International Comparisons of National R&D Trends

Absolute levels of R&D expenditures are indicators of the breadth and scope of a nation's S&T activities and are a harbinger of future growth and productivity. Indeed, investments in the R&D enterprise strengthen the technological base on which economic prosperity increasingly depends worldwide. The relative strength of a particular country's current and future economy and the specific scientific and technological areas in which a country excels, are further revealed through comparison with other major R&D-performing countries. This section provides comparisons of international R&D spending patterns.[47] It examines absolute and relative expenditure trends, contrasts performer and source structural patterns, reviews the foci of R&D activities within sectors, and looks at government research-related priorities. Although R&D performance patterns by sector are broadly similar across countries, national sources of support differ considerably. In nearly all OECD countries, government has provided a declining share of all R&D funding during the past decade, whereas the industrial share of the funding total has increased considerably. The relative emphasis of industrial R&D efforts, however, differ across countries, as do governmental R&D priorities and academic S&E field research emphases. Reflecting an overall pattern of R&D internationalization, foreign sources of R&D funding have been increasing in many countries.

Absolute Levels of Total R&D Expenditures

The worldwide distribution of R&D performance is concentrated in relatively few industrialized nations. Of the $518 billion in estimated 1998 R&D expenditures for the 30 OECD countries, fully 85 percent is expended in only 7 countries (Organisation for Economic Co-operation and Development 2000a).[48] These estimates are based on reported R&D investments (for defense and civilian projects) converted to U.S. dollars with purchasing power parity (PPP) exchange rates.[49] See sidebar, "Purchasing Power Parities: Preferred Exchange Rates for Converting International R&D Data."

The United States accounts for roughly 44 percent of all OECD member countries' combined R&D investments; U.S. R&D investments continue to outdistance by 150 percent R&D investments made in Japan, the second largest R&D-performing country. The United States not only spent more money on R&D activities in 1999 than any other country but also spent as much by itself as the rest of the G-7 countries (Canada, France, Germany, Italy, Japan, and the United Kingdom) combined. (See figure 4-26 and appendix table 4-40 for inflation-adjusted PPP R&D totals for OECD and G-7 countries.) In terms of other large R&D performers, only South Korea accounts for a substantial share of the OECD total (a remarkable 3.8 percent in 1998, which is higher than the amounts expended in either Canada or Italy). In only four other countries (the Netherlands, Australia, Sweden, and Spain) do R&D expenditures exceed 1 percent of the OECD R&D total (OECD 2000a).[50]

In terms of relative shares, U.S. R&D spending in 1985 reached historical highs of 53 percent of the G-7 total and 48 percent of all OECD R&D.[51] As a proportion of the G-7 total, U.S. R&D expenditures declined steadily to a low of 49 percent in 1992. Since then, U.S. R&D has climbed to its 1999 level, a 53 percent G-7 share. (See figure 4-26 for actual expenditure totals.) Conversely, R&D spending in the United States was equivalent to 112 percent of spending in non-U.S. G-7 countries and to approximately 80 percent of all other OECD countries' R&D expenditures in 1999.

Initially, most of the U.S. improvement since 1993 relative to the other G-7 countries resulted from a worldwide slowing in R&D performance that was more pronounced in other countries. Although U.S. R&D spending stagnated or declined for several years in the early to mid-1990s, the reduction in real R&D spending in most of the other large R&D-performing countries was more striking. In Japan, Germany, and Italy, inflation-adjusted R&D spending fell for three consecutive years (1992, 1993, and 1994) at a rate of decline that exceeded similarly falling R&D spending in the United States.[52] In fact, large and small industrialized countries worldwide experienced substantially reduced R&D spending in the early 1990s (OECD 2000a). For most of these countries, economic recessions and general budgetary constraints slowed both industrial and government sources of R&D support. More recently, R&D spending has rebounded in several G-7 countries, as has R&D spending in the United States. Yet since annual R&D growth generally has been stronger in the United States than elsewhere and has even slowed to a standstill in Japan according to the most recently available statistics (see figure 4-27), the difference between the United States and the other G-7 countries' combined R&D spending has continued to widen.

Concurrent with the latest years' increase in the U.S. share of the G-7 countries' R&D performance, a similar increase has been seen in the U.S. share of all OECD countries' R&D spend-

[47]Most of the R&D data presented here are from reports to OECD, the most reliable source of such international comparisons. A high degree of consistency characterizes the R&D data reported by OECD, with differences in reporting practices among countries affecting their R&D/GDP ratios by no more than an estimated 0.1 percentage point (International Science Policy Foundation 1993). Nonetheless, an increasing number of non-OECD countries and organizations now collect and publish internationally comparable R&D statistics, which are reported at various points in this chapter.

[48]Current OECD members are Australia, Austria, Belgium, Canada, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, South Korea, Luxembourg, Mexico, the Netherlands, New Zealand, Norway, Poland, Portugal, Slovakia, Spain, Sweden, Switzerland, Turkey, the United Kingdom, and the United States.

[49]Although PPPs technically are not equivalent to R&D exchange rates, they better reflect differences in countries' research costs than do market exchange rates.

[50]Although countries other than members of the OECD also fund and perform R&D, with the exception of just a handful, most of these national R&D efforts are comparatively small. For example, in 1997 total R&D expenditures in China and Russia were $24.7 billion and $10.3 billion (PPP dollars) and nondefense R&D in Israel totaled $2.5 billion PPP (OECD 2000c). Among non-OECD members of Red Iberomericana de Indicadores de Ciencia y Tecnologia (RICYT), the largest R&D expenditures are reported for Brazil ($9.2 billion U.S. at market exchange rates), Argentina ($1.1 billion), Chile ($0.5 billion), and Colombia ($0.4 billion) (RICYT 2001). The combined R&D expenditures of these seven countries (approximately $50 billion) would raise the OECD world total by about 10 percent, and about one-half would be derived from China alone.

[51] OECD maintains R&D expenditure data that can be divided into three periods: (1) 1981 to the present, which are properly annotated and of good quality; (2) 1973 to 1980, which are probably of reasonable quality, for which some metadata are available; and (3) 1963 to 1972, about which there are serious doubts for most OECD countries (with notable exceptions of the United States and Japan), many of which launched their first serious R&D surveys in the mid-1960s. The analyses in this chapter are limited to data for 1981 and later years.

[52] The United Kingdom similarly experienced three years of declining real R&D expenditures, but its slump took place in 1995, 1996, and 1997. The falling R&D totals in Germany were partly a result of specific and intentional policies to eliminate redundant and inefficient R&D activities and to integrate the R&D efforts of the former East Germany and West Germany into a united German system.

Purchasing Power Parities: Preferred Exchange Rates for Converting International R&D Data

Comparisons of international R&D statistics are hampered because each country's R&D expenditures are denominated in its home currency. Two approaches are commonly used to normalize the data and facilitate aggregate R&D comparisons: dividing R&D by gross domestic product, which results in indicators of relative effort according to total economic activity and circumvents the problem of currency conversion, and converting all foreign-denominated expenditures to a single currency, which results in indicators of absolute effort. The first method is a straightforward calculation that permits only gross national comparisons. The second method permits absolute-level comparisons and analyses of countries' sector- and field-specific R&D investments, but it entails choosing an appropriate currency conversion series.

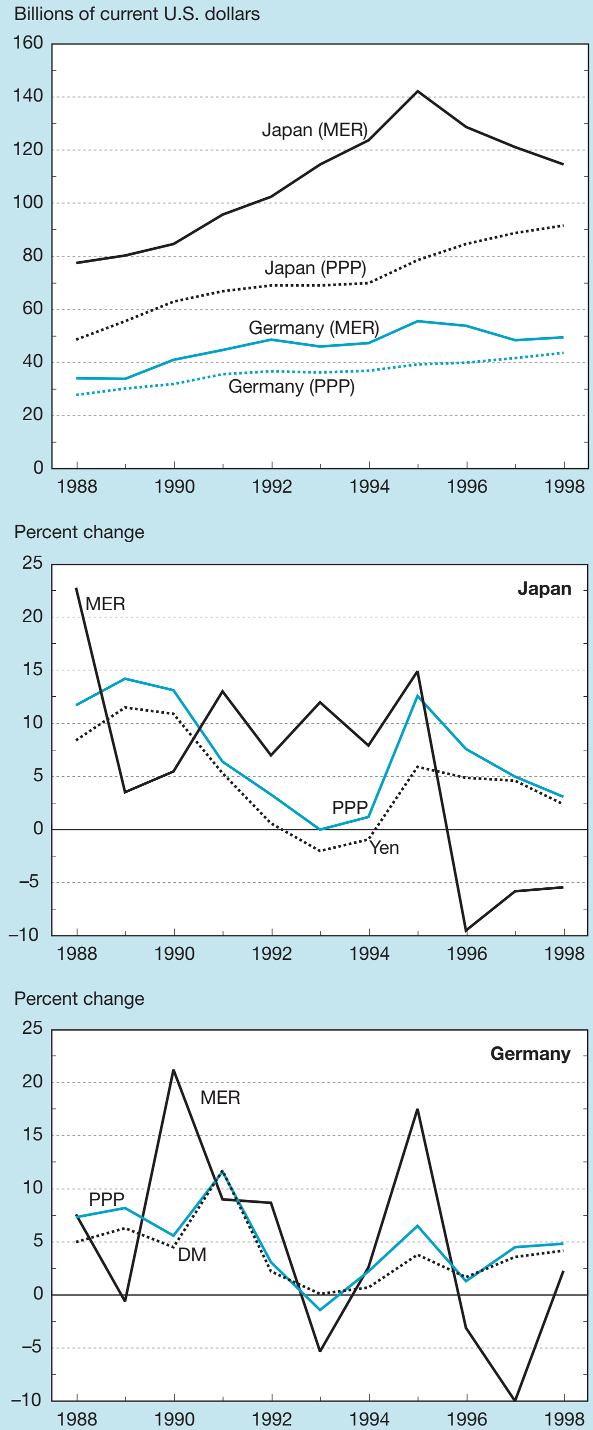
Market Exchange Rates Versus Purchasing Power Parity Rates

Because (for all practical purposes) no widely accepted R&D-specific exchange rates exist, the choice is between market exchange rates (MERs) (International Monetary Fund 1999) and purchasing power parities (PPPs) (OECD 2000a). These rates are the only series consistently compiled and available for a large number of countries over an extended period of time.

Market Exchange Rates—At their best, MERs represent the relative value of currencies for goods and services that are traded across borders; that is, MERs measure a currency's relative international buying power. Sizable portions of most countries' economies do not engage in international activity, however, and major fluctuations in MERs greatly reduce their statistical utility. MERs also are vulnerable to a number of distortions, including currency speculation, political events such as wars or boycotts, and official currency intervention, which have little or nothing to do with changes in the relative prices of internationally traded goods.

Purchasing Power Parity Rates—Because of the MER shortcomings described above, the alternative currency conversion series of PPPs has been developed (Ward 1985). PPPs take into account the cost differences across countries of buying a similar basket of goods and services in numerous expenditure categories, including nontradables. The PPP basket is, therefore, representative of total GDP across countries. When the PPP formula is applied to current R&D expenditures of other major performers, such as Japan and Germany, the result is a substantially lower estimate of total R&D spending than that given by MERs. (See figure 4-25.) For example, Japan's R&D in 1998 totaled \$92 billion based on PPPs and \$115 billion based on MERs, and the

Figure 4-25.
R&D expenditures and annual changes in R&D estimates, Japan and Germany



MER = market exchange rate; PPP = purchasing power parity; DM = deutsche mark

See appendix tables 4-2 and 4-40.

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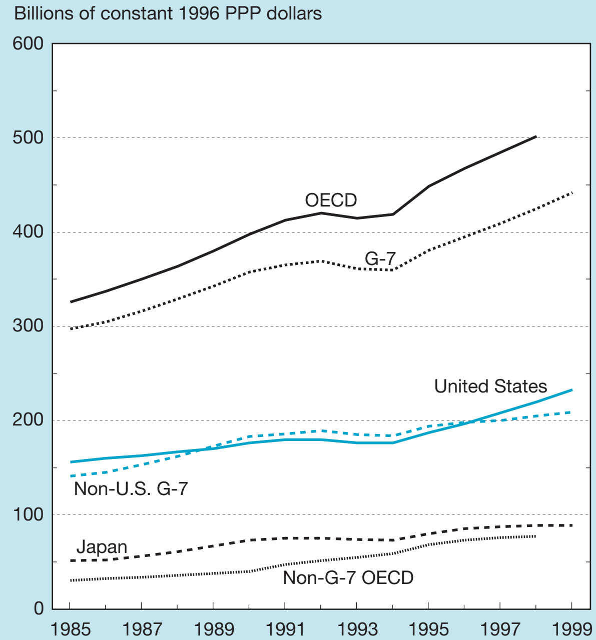
German R&D expenditure was $44 billion on PPPs and $50 billion on MERs. (By comparison, the U.S. R&D expenditure was $227 billion in 1998.)

PPPs are the preferred international standard for calculating cross-country R&D comparisons wherever possible and are used in all official OECD R&D tabulations. Unfortunately, they are not available for all countries and currencies. They are available for all OECD countries, however, and are therefore used in this report.

Exchange Rate Movement Effects

Although the difference is considerable between what is included in GDP-based PPP items and R&D expenditure items, the major components of R&D costs, fixed assets and the wages of scientists, engineers, and support personnel, are more suitable to a domestic converter than to one based on foreign trade flows. Exchange rate movements bear little relationship to changes in the cost of domestically performed R&D. (See figure 4-25.) When annual changes in Japan's and Germany's R&D expenditures are converted to U.S. dollars with PPPs, they move in tandem with such funding denominated in their home currencies. Changes in dollar-denominated R&D expenditures converted with MERs exhibit wild fluctuations that are unrelated to the R&D purchasing power of those investments. MER calculations indicate that, between 1988 and 1998, German and Japanese R&D expenditures each increased twice by 15 percent or more. In reality, nominal R&D growth was only one-fourth to one-third those rates in either country during this period. PPP conversions generally mirror the R&D changes denominated in these countries' home currencies.

Figure 4-26.
U.S., G-7, and OECD countries' R&D expenditures



OECD = Organisation for Economic Co-operation and Development; PPP = purchasing power parity

NOTE: Non-U.S. G-7 countries are Canada, France, Germany, Italy, Japan, and the United Kingdom.

See appendix table 4-40. *Science & Engineering Indicators – 2002*

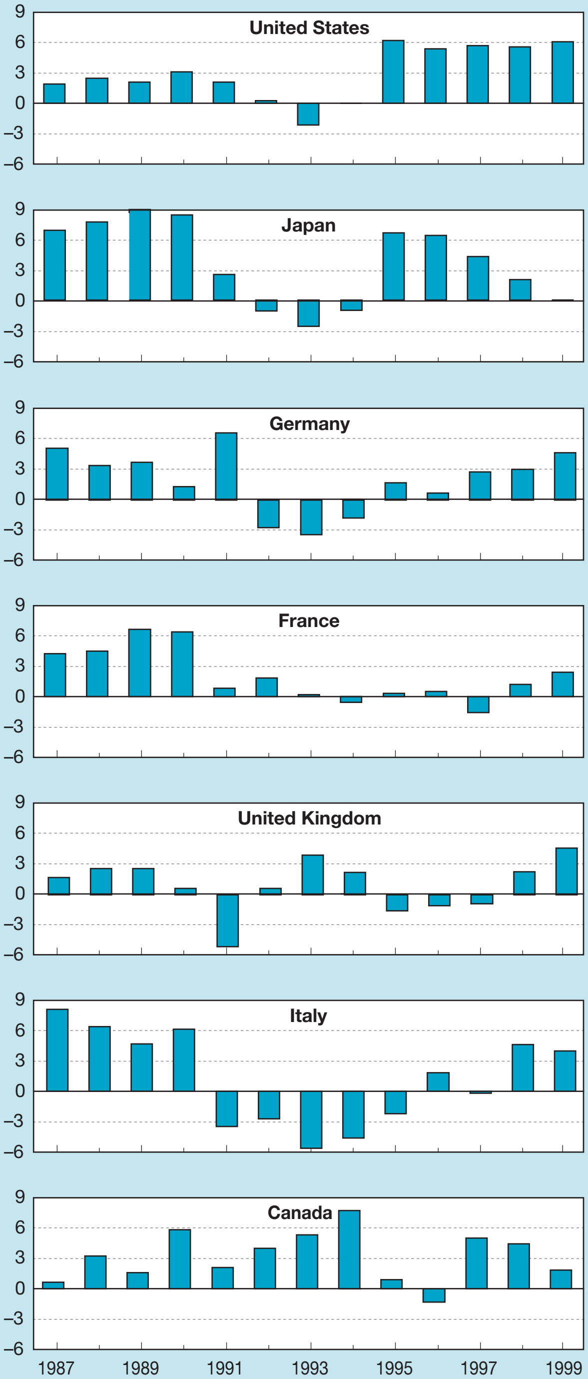
ing. In 1985, the United States accounted for 48 percent of the R&D reported by OECD countries; by 1995, the U.S. share had dropped to 42 percent of the OECD R&D total. Part of this share reduction (perhaps up to 2 percentage points) resulted from the addition of several countries to OECD membership (thereby increasing the OECD R&D totals); worldwide growth in R&D activities, however, was a greater contributing factor to the loss of R&D share experienced by the United States. Since then, the U.S. share has climbed back to 44 percent of the OECD total in 1999, more a result of robust R&D growth in the United States than a result of the significant changes under way in the other OECD countries.

Trends in Total R&D/GDP Ratios

One of the first (Steelman 1947) and now most widely used indicators of a country's commitment to growth in scientific knowledge and technology development is the ratio of R&D spending to GDP. (See figure 4-28.) For most of the G-8 countries (that is, the G-7 countries plus the Russian Federation), the latest R&D/GDP ratio is no higher now than it was at the start of the 1990s, which ushered in a period of slow growth or decline in their overall R&D efforts. The ways in which different countries have reached their current ratios vary considerably, however.[53] The United States and Japan reached 2.7 and 2.8 percent, respectively, in 1990–91. As a result of reduced or level spending by industry and government in both countries, the R&D/GDP ratios declined several tenths of a percentage point, to 2.4 and 2.6, respectively, in 1994 before rising again to 2.6 and 3.0 percent. Growth in industrial R&D accounted for much of the recovery in each of these countries. Electrical equipment, telecommunications, and computer services companies have reported some of the strongest R&D growth since 1995 in the United States. Growth in pharmaceutical R&D also has been substantial. In Japan, spending increases were highest in the electronics, machinery, and automotive sectors and appear to be associated mainly with a wave of new digital technologies (Industrial Research Institute 1999). However, the steady increase in Japan's R&D/GDP ratio since 1994 is also partially a result of anemic economic conditions overall: GDP fell in both 1998 and 1999,

[53] A country's R&D spending and therefore its R&D/GDP ratio is a function of several factors in addition to its commitment to supporting the R&D enterprise. Especially because the majority of R&D is performed by industry in each of these countries, the structure of industrial activity can be a major determinant of a country's R&D/GDP ratio. For example, economies with high concentrations in manufacturing (which traditionally have been more R&D intensive than nonmanufacturing or agricultural economies) have different patterns of R&D spending. See "Industry Sector" for further discussion of such considerations.

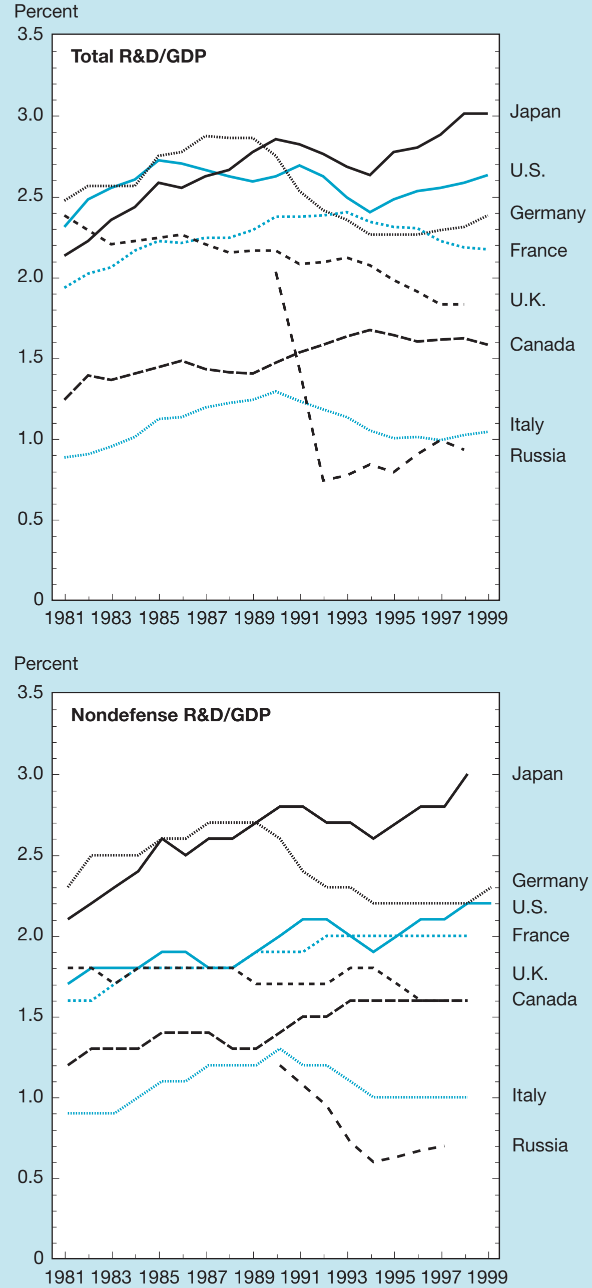
Figure 4-27.
Rates of change in total inflation-adjusted R&D spending



NOTE: The inflation-adjusted R&D expenditures reflected in this graph are denominated in foreign currencies deflated by the countries' own GDP price deflators and therefore are not distorted by exchange rate conversions.

See appendix table 4-40. *Science & Engineering Indicators – 2002*

Figure 4-28.
R&D as percentage of GDP, G-8 countries



See appendix tables 4-40 and 4-41.

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so that even level R&D spending resulted in a slight increase in its R&D ratio (OECD 2000a).

Among the remaining six G-8 countries, two (Germany and Russia) display recent increases in their economies' R&D intensity, and four (the United Kingdom, France, Italy, and Canada) report an R&D/GDP ratio that has remained stagnant or continues to decline. In Germany, the R&D/GDP ratio fell from 2.9 percent at the end of the 1980s, before reunification, to 2.3 percent in 1993 before rising to its current level of 2.4 percent. By comparison, this macro-R&D

indicator continues to slip slightly in France and the United Kingdom to their current levels of 2.2 and 1.9 percent, respectively, and has fluctuated narrowly at 1.0 and 1.6 percent in Italy and Canada, respectively, for the past five years or longer. The end of the cold war and collapse of the Soviet Union had a drastic effect on Russia's R&D enterprise. R&D spending in Russia was estimated at 2.0 percent of GDP in 1990; that figure plummeted to 1.4 percent in 1991 and then tumbled further to 0.7 percent in 1992. Moreover, the severity of this R&D decline is masked somewhat: although the R&D share was falling, it also was a declining share of a declining GDP. By 1999, the R&D/GDP ratio in Russia had inched back to about 1.0 percent, although the country continues to experience severe reductions in its R&D spending.

Overall, the United States ranked fifth among OECD countries in terms of reported R&D/GDP ratios for the 1996–99 period. (See text table 4-13.) Sweden leads all countries with 3.7 percent of its GDP devoted to R&D, followed by Japan (3.0 percent), Finland (2.9 percent), and Switzerland (2.7 percent). In general, nations in Southern and Eastern Europe tend to have R&D/GDP ratios below 1.5 percent, whereas Nordic nations and those in Western Europe report R&D spending shares greater than 1.5 percent. In a broad sense, the reason for such patterns has much to do with overall funding patterns and macroeconomic structures. In practically all OECD countries, the business sector finances most of the R&D. However, OECD countries with relatively low R&D/GDP ratios tend to be relatively low-income countries, and government funding tends to provide a larger proportion of the R&D support than it provides in the high R&D/GDP ratio countries. Furthermore, the private sector in such low-income countries often consists of low-technology industries, resulting in low overall R&D spending and, therefore, low R&D/GDP ratios. Indeed, a strong link exists between countries with high incomes that emphasize the production of high-technology goods and services and those that invest heavily in R&D activities (OECD 2000e).[54]

Text table 4-13.
R&D percentage of gross domestic product

Sweden (1997)	3.70	Brazil (1996)	0.91
Japan (1999)	3.01	Spain (1999)	0.89
Finland (1998)	2.89	Slovak Republic (1998)	0.86
Switzerland (1996)	2.73	Cuba (1999)	0.83
United States (1999)	2.63	Poland (1999)	0.75
South Korea (1998)	2.55	China (1998)	0.69
Israel (1997)	2.54	South Africa (1998)	0.69
Germany (1999)	2.38	Hungary (1999)	0.68
France (1999)	2.17	Chile (1997)	0.63
Denmark (1999)	1.99	Portugal (1997)	0.62
Belgium (1999)	1.98	Romania (1998)	0.54
Taiwan (1998)	1.97	Greece (1997)	0.51
Netherlands (1998)	1.95	Turkey (1997)	0.49
Iceland (1999)	1.88	Argentina (1999)	0.47
United Kingdom (1999)	1.87	Colombia (1997)	0.41
Canada (1999)	1.85	Mexico (1997)	0.34
Austria (1999)	1.82	Panama (1998)	0.33
Norway (1999)	1.73	Bolivia (1999)	0.29
Australia (1998)	1.49	Uruguay (1999)	0.26
Singapore (1997)	1.47	Malaysia (1996)	0.22
Slovenia (1997)	1.42	Trinidad and Tobago (1997)	0.14
Ireland (1997)	1.39	Nicaragua (1997)	0.13
Czech Republic (1999)	1.27	Ecuador (1998)	0.08
Costa Rica (1996)	1.13	El Salvador (1998)	0.08
New Zealand (1997)	1.13	Peru (1997)	0.06
Italy (1999)	1.04	**Total OECD** (1998)	2.18
Russian Federation (1999)	1.06	**European Union** (1998)	1.81

NOTES: Civilian R&D only for Israel and Taiwan. Data are presented for the latest available year in parentheses.

SOURCES: Organisation for Economic Co-operation and Development (OECD), Main Science and Technology Indicators database (April 2001); Pacific and Economic Cooperation Council (1999); OECD, *R&D Efforts in China, Israel, and Russia: Some Comparisons With OECD Countries,* (CCNM/DSTI/EAS, Paris, 2000); Centre for Science Research and Statistics (CSRS), *Russian Science and Technology at a Glance: 2000* (Moscow 2001); Red Iberomericana de Indicadores de Ciencia y Tecnologia (Iberomerican Network of Science & Technology Indicators) (RICYT), *Principales Indicadores de Ciencia y Tecnologia 2000* (Buenos Aires, Argentina 2001); and national sources.

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Outside the European region, R&D spending has intensified considerably since the early 1990s. Several Asian countries, most notably South Korea and China, have been particularly aggressive in expanding their support for R&D and S&T-based development. In Latin America and the Pacific region, other non-OECD countries also have attempted to increase R&D investments substantially during the past several years. Even with recent gains, however, most non-European (non-OECD) countries invest a smaller share of their economic output on R&D than do OECD members (with the exception of Israel, whose reported 2.5 percent nondefense R&D/GDP ratio ranks seventh in the world). With the apparent exception of Costa Rica, all Latin American countries for which such data are available report R&D/GDP ratios below 1 percent. (See text table 4-13.) This distribution is consistent with broader indicators of economic growth and wealth. However, many of these countries also report additional S&T-related expenditures on human resources training and S&T infrastructure development that are not captured in R&D and R&D/GDP data (Red Iberomericana de Indicadores de Ciencia y Tecnologia 2001).

Nondefense R&D Expenditures and R&D/GDP Ratios

As a result of concerns related to national scientific progress, standard-of-living improvements, economic competitiveness, and commercialization of research results, attention has shifted from nations' total R&D activities to nondefense R&D expenditures as indicators of scientific and technological strength. Indeed, conclusions about a country's relative standing may differ dramatically, depending on whether total R&D expenditures are considered or defense-related expenditures are excluded from the totals; for some countries, the relative emphasis has shifted over time. Among

[54] See OECD (1999b) for further discussion of these and other broad R&D indicators for OECD countries.

G-8 countries, the inclusion of defense R&D has little impact on R&D totals for Japan, Germany, Italy, and Canada, where defense R&D represents 5 percent or less of the national total. In other countries, defense has accounted for a more significant, although since the end of the cold war declining, proportion of the national R&D effort. Between 1988 and 1998, the defense share of the R&D total:

- has fallen from 31 to 15 percent in the United States,
- has fallen from 21 to 7 percent in France,
- has fallen from 17 to 12 percent in the United Kingdom, and
- accounts for approximately 25 percent of the 1998 Russian R&D total.

Consequently, if current trends persist, the distinction between defense and nondefense R&D expenditures in international comparisons may become less important. In absolute dollar terms, the U.S. nondefense R&D spending is still considerably larger than that of its foreign counterparts. In 1998 (the latest year for which comparable international R&D data are available from most OECD countries), U.S. nondefense R&D was more than twice that of Japan and was equivalent to 94 percent of the non-U.S. G-7 countries' combined nondefense R&D total. (See appendix table 4-41.)

In terms of R&D/GDP ratios, the relative position of the United States is somewhat less favorable for this nondefense metric compared with those ratios for all R&D combined. Japan's nondefense R&D/GDP ratio (3.0 percent) exceeded that of the United States (2.2 percent) in 1998, as it has for years. (See figure 4-28 and appendix table 4-41.) The nondefense R&D ratio of Germany (2.3 percent in 1999) slightly exceeded that of the United States (again, in contrast to total R&D). The 1998 nondefense ratio for France (2.0 percent) was slightly below the U.S. ratio; ratios for the United Kingdom and Canada (each at 1.6 percent) and for Italy (1.0 percent) were considerably lower. The nondefense R&D/GDP ratio for Russia was nearly one-third (0.7 percent) the U.S. ratio.

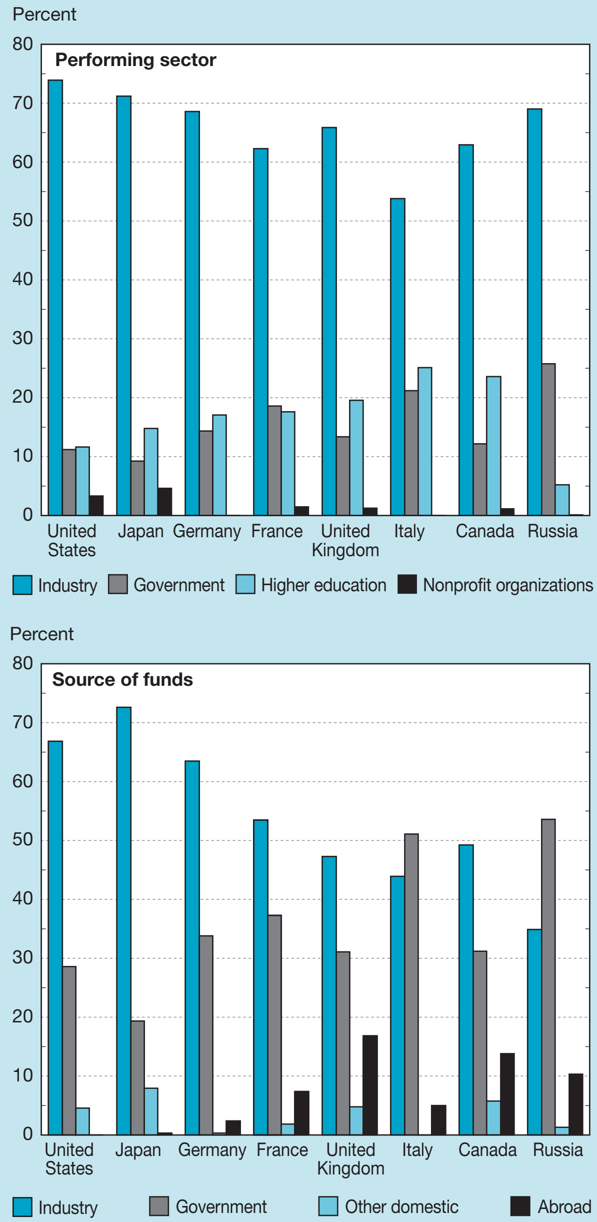
International R&D by Performer, Source, and Character of Work

Broad Sector Patterns

Although marked differences are observed in the financing and performance of R&D among both OECD and non-OECD countries, similarities also are observed in R&D patterns for the G-8 countries. Government and industry account for roughly 80 percent or more of the R&D funding in each of these eight countries, although the respective contributions vary substantially across countries.[55] The industrial sector provided more than 70 percent of R&D funds in Japan, 67 percent in the United States, 64 percent in Germany, 54 percent in France; and between 44 and 49 percent in the United Kingdom, Italy, and Canada. (See figure 4-29.) In Russia, industry provided approximately 35 percent of the nation's R&D funding. Government provided the largest share (54 percent) of Russia's R&D total, as it did in Italy (at 51 percent of the national R&D effort). In the remaining six countries, government was the second largest source of R&D funding, ranging between 19 percent (in Japan) and 37 percent (in France) of the total. In each of these eight countries, government provided the largest share of the funds used for academic R&D performance. (See appendix table 4-42.)

[55] In accordance with international standards, sources of funding are attributed to the following sectors: all levels of government combined, business enterprises, higher education, private nonprofit organizations, and funds from abroad. The taxonomy used in presenting U.S. R&D expenditures elsewhere in this chapter differs somewhat.

Figure 4-29.
R&D expenditures by performer and source, G-8 countries



NOTES: Japan, France, United Kingdom, and Russia data for 1998. U.S., Germany, Italy, and Canada data for 1999.

See appendix table 4-42. *Science & Engineering Indicators – 2002*

The industrial sector dominates R&D performance in each of the G-8 countries. (See figure 4-29.) Industry performance shares for the 1998–99 period ranged from a little more than 70 percent in the United States and Japan to less than 54 percent in Italy. Industry's share was between 62 and 69 percent in France, Canada, the United Kingdom, Germany, and Russia. Most of the industrial R&D performance in these countries was funded by industry. Government's share of funding for industry R&D performance ranged from as little as 2 percent in Japan to 43 percent in Russia. (See appendix table 4-42.) In the other G-8 countries, the government funding share of industrial R&D ranged narrowly between 5 and 13 percent.

In most of these countries, the academic sector was the next largest R&D performer (at about 12 to 25 percent of the performance total in each country).[56] Academia often is the primary location of research (as opposed to R&D) activities, however. Government was the second largest R&D performing sector in France (which included spending in some sizable government laboratories), as it was in Russia (accounting for 26 percent of that nation's R&D effort).

[56] The national totals for Europe, Canada, and Japan include the research component of general university fund (GUF) block grants (not to be confused with basic research) provided by all levels of government to the academic sector. Therefore, at least conceptually, the totals include academia's separately budgeted research and research undertaken as part of university departmental R&D activities. In the United States, the Federal Government generally does not provide research support through a GUF equivalent, preferring instead to support specific, separately budgeted R&D projects. On the other hand, a fair amount of state government funding probably does support departmental research at public universities in the United States. Data on departmental research, considered an integral part of instructional programs, generally are not maintained by universities. U.S. totals are most certainly underestimated relative to the R&D effort reported for other countries.

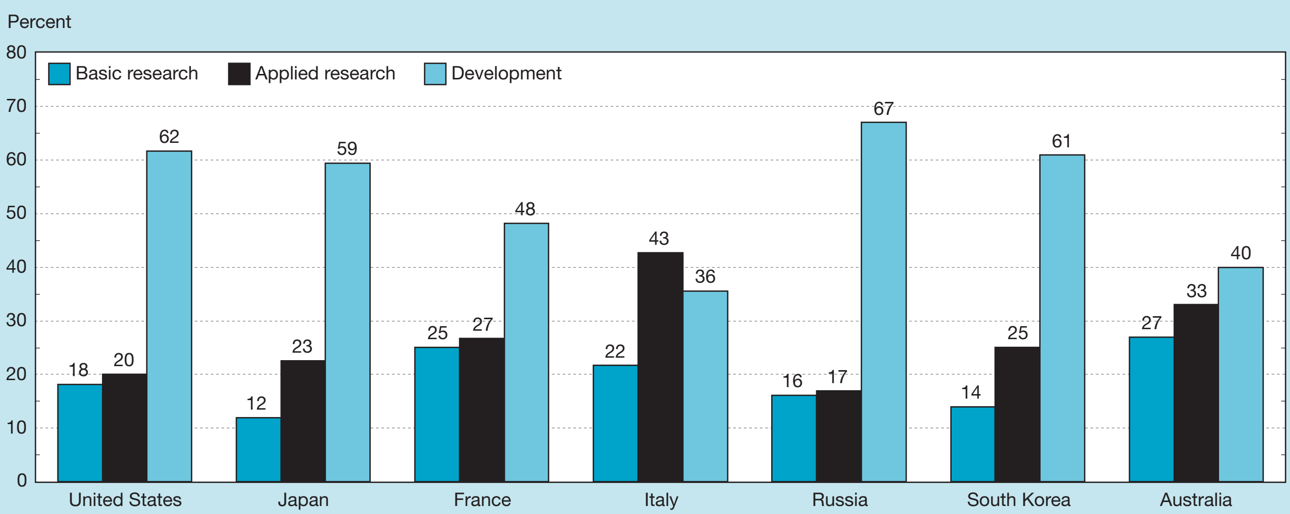
Character of R&D Effort

Not all of the G-8 countries categorize their R&D expenditures into basic research, applied research, or development categories, and for several countries that do use this taxonomy, the data are somewhat dated (OECD 2000b). In fact, only 6 of the 30 OECD members (and Russia) have reported their countries' character of work shares for 1998 or later. R&D classification by character of work probably involves a greater element of subjective assessment than other R&D indicators. See sidebar, "Choice of the 'Right' R&D Taxonomy Is a Historical Concern." Rather than resulting from surveys, the data often are estimated in large part by national authorities.[57] Nonetheless, where these data exist, they indicate the relative emphasis that a country places on supporting fundamental scientific activities—the seed corn of economic growth and technological advancement.

The United States expends approximately 18 percent of its R&D on activities that performers classify as basic research. (See figure 4-30.) About one-half of this research is funded by the Federal Government and performed in the academic sector. The largest share of this basic research effort is conducted in support of life sciences. Basic research accounts for comparatively smaller amounts of the national R&D per-

[57] The magnitude of the amounts estimated as basic research also is affected by how R&D expenditures are themselves estimated by national authorities. International R&D survey standards recommend that both capital and current expenditures be included in the R&D estimates, including amounts expended on basic research. Each of the non-U.S. countries displayed in figure 4-30 includes capital expenditures on fixed assets at the time they took place (OECD 1999b). All U.S. R&D data reported in the figure include depreciation charges instead of capital expenditures. U.S. R&D plant data (not shown in the figure) are distinct from current fund expenditures on R&D.

Figure 4-30.
Distribution of R&D expenditures by character of work in selected countries: 1998



NOTES: The character of work for 6 percent of Japan's R&D is unknown. Details may not sum to total because of rounding.

SOURCES: Organisation for Economic Co-operation and Development (OECD), 2000b; Centre for Science Research and Statistics (CSRS), 2001.

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Choice of the "Right" R&D Taxonomy Is a Historical Concern

With the following words, written more than 50 years ago, Vannevar Bush (1945) laid the basis in his seminal report, *Science—The Endless Frontier,* for what eventually became known (and perhaps was unfairly derided) as the linear model of innovation:

"Scientific research may be divided into the following broad categories: (1) pure research, (2) background research, and (3) applied research and development. The boundaries between these categories are by no means clear-cut and it is frequently difficult to assign a given investigation to any single category. On the other hand, typical instances are easily recognized, and study reveals that each category requires different institutional arrangements for maximum development." (p. 81.)… "Basic research…creates the fund from which the practical applications of knowledge must be drawn. New products and new processes do not appear full-grown. They are founded on new principles and new conceptions, which in turn are painstakingly developed by research in the purest realms of science." (p. 19.)

Bush's model somewhat simplistically depicts innovation as a three-step process whereby (1) scientific breakthroughs from the performance of basic research (2) lead to applied research, which (3) leads to the development or application of applied research to commercial products, processes, and services. Although it is quite unlikely that either scientific or statistical experts ever really believed that such a model captured the complex relationships between science, technology, and innovation, it did (and still does) lend itself to the collection and analysis of data for policymaking purposes.

Most of the criticism surrounding the inappropriateness of the basic research, applied research, and development categories that are used in practically all R&D data collection efforts (see sidebar, "Definitions of Research and Development," at the beginning of this chapter) focus on the lack of clear boundaries between basic research and applied research.* This debate took form ever since Bush first differentiated "basic research" (a term he used interchangeably with "pure research") as that which is performed without thought of specific practical ends from applied research, the function of which is to provide "complete answers" to practical problems. A number of proposals have arisen over the years to replace, or supplement, the basic/applied research taxonomic categories, including fundamental versus strategic research, exploratory versus programmatic research, curiosity-driven versus mission-oriented research—to name just a few.†

Indeed, in the last published version (OECD 1994) of the *Frascati Manual* (international standards and guidelines for conducting R&D surveys), the option of collecting separate data on "pure basic research" and "oriented basic research" was introduced. To date, few countries have chosen to collect research expenditure data with these, or similar, reporting refinements. More generally, none of the proposed alternatives has gained a consensus in either the scientific, political, or statistical communities; each proposed alternative suffers from its own shortcomings which are as least as problematic as the taxonomic categories that would be replaced. On a more historical note, Bush himself was not particularly concerned about the precision of the definitions he used. Rather, he simply wanted to establish a framework that offered the best chance for basic research to receive special protection and, more important, ensured government financial support.

*It is just as likely, however, that the distinctions between applied research and development and between development and related (for example, routine testing and evaluation) and downstream (for example, preproduction) activities are subject to their own reporting complexities.

†One of the more recent well-known alternative taxonomy paradigms was developed by the late David Stokes (1997) and depicted in *Pasteur's Quadrant: Basic Science and Technological Innovation*. Stokes suggested multiple research categories: pure basic research (work inspired by the quest for basic understanding but not by potential use), purely applied research (work motivated only by potential use), and strategic research (work inspired by both potential use and fundamental understanding). Stokes characterized Louis Pasteur's research on the microbiological process of disease in the late 19th century as strategic research.

formance efforts in the Russian Federation (16 percent); South Korea (14 percent), which is currently the sixth largest R&D-performing member of OECD; and Japan (12 percent). Compared with patterns in the United States, however, a considerably greater share is funded for engineering research activities in each of these three countries. Conversely, basic research accounts for more than 20 percent of total R&D performance reported in Italy, France, and Australia.[58]

In contrast to spending patterns reported for most countries, spending on applied research activities accounts for the largest proportion (43 percent) of Italy's R&D total. In each of the other countries shown here, development accounted for the largest share of national totals (approximately 60 percent but as little as 40 percent of total in Australia), with most of the experimental development work under way in their respective industrial sectors.

Higher Education Sector

Source of Funds. In many OECD countries, the academic sector is a distant second to industry in terms of the national R&D performance effort. Among G-8 countries, universities

[58]The most current character of work data available from OECD sources for Germany are for 1993. The United Kingdom compiles such data only for the industry and government sectors, not for higher education or its nonprofit sector, the traditional locus of basic research activities.

account for as little as 5 percent of Russia's R&D total to upward of a 25 percent share in Italy.[59] For most of these countries, the government is now, and historically has been, the largest source of academic research funding. However, in each of these countries for which historical data exist (the exception being Russia), the government financing share has declined during the past 20 years, and industry as a source of university R&D funding has increased. Specifically, the government share, including both direct government support for academic R&D and the R&D component of block grants to universities,[60] has fallen by 8 percentage points or more in six of the G-7 countries since 1981 (the exception being Italy, in which the government share has dipped from 96 to 94 percent of the academic R&D total). By comparison, and as an indication of an overall pattern of increased university-firm interactions (often intending to promote the commercialization of university research), the funding proportion from industry sources for these seven countries combined climbed from 2.5 percent of the academic R&D total in 1981, to 5.4 percent in 1990, to 6.4 percent in 1998. In Germany and Canada, almost 11 percent of university research is now funded by industry. (See text table 4-14.)

S&E Fields. As noted in the discussion on the character of the R&D effort, the national emphases in particular S&E fields differ across countries. Where they are collected at all, most of the internationally comparable data on field-specific R&D are reported for the higher education sector. Although difficult to generalize, it would appear that most countries supporting a substantial level of academic R&D (defined at $1 billion PPPs in 1998) devote a relatively larger proportion of their R&D for engineering, social sciences, and humanities than does the United States. (See text table 4-15.) Conversely, the U.S. academic R&D effort emphasizes the medical sciences and natural sciences relatively more than do many other OECD countries.[61] The latter observation is consistent with the overall U.S. relative R&D emphases in health and biomedical sciences for which NIH and U.S. pharmaceutical companies are known.

Text table 4-14.
Academic R&D expenditures, by country and source of funds
(Percentages)

Country and source of funds	1981	1990	1999
Canada			
Government	79.8	73.2	66.4
Other	16.4	20.9	22.8
Industry	3.9	5.9	10.8
France			
Government	97.7	92.9	88.9
Other	1.0	2.2	7.7
Industry	1.3	4.9	3.4
Germany			
Government	98.2	92.1	87.5
Other	0.0	0.0	2.0
Industry	1.8	7.9	10.6
Italy			
Government	96.2	96.7	94.4
Other	1.1	0.9	0.9
Industry	2.7	2.4	4.8
Japan			
Government	57.7	51.2	49.1
Other	41.3	46.5	48.5
Industry	1.0	2.3	2.3
United Kingdom			
Government	81.3	73.5	64.4
Other	15.9	19.0	28.3
Industry	2.8	7.6	7.3
United States			
Government	74.1	66.9	65.6
Other	21.5	26.2	26.9
Industry	4.4	6.9	7.3

NOTES: Canada data are for 1983; France, Japan, and United Kingdom data are for 1998.

SOURCE: Organisation for Economic Co-operation and Development (OECD), *Basic Science and Technology Statistics* (Paris, March 2000).

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Industry Sector

Sector Focus. Industrial firms account for the largest share of the total R&D performance in each of the G-8 countries. However, the purposes to which the R&D is applied differ somewhat, depending on the overall industrial composition of the economy. Furthermore, the structure of industrial activity can itself be a major determinant of the level and change in a country's industrial R&D spending. Variations in such spending can result from differences in absolute output, industrial structure, and R&D intensity. Countries with the same size economy could have vastly different R&D expenditure levels (and R&D/GDP ratios). Differences might depend on the share of industrial output in the economy, on whether the industries that account for the industrial output are traditional

[59]Country data are for 1998 or 1999. (See appendix table 4-42.)

[60]Whereas GUF block grants are reported separately for Japan, Canada, and European countries, the United States does not have an equivalent GUF category. In the U.S., funds to the university sector are distributed to address the objectives of the Federal agencies that provide the R&D funds. Nor is GUF equivalent to basic research. The treatment of GUF is one of the major areas of difficulty in making international R&D comparisons. In many countries, governments support academic research primarily through large block grants that are used at the discretion of each individual higher education institution to cover administrative, teaching, and research costs. Only the R&D component of GUF is included in national R&D statistics, but problems arise in identifying the amount of the R&D component and the objective of the research. Government GUF support is in addition to support provided in the form of earmarked, directed, or project-specific grants and contracts (funds for which can be assigned to specific socioeconomic categories). In the United States, the Federal Government (although not necessarily state governments) is much more directly involved in choosing which academic research projects are supported than are national governments in Europe and elsewhere. In each of the European G-7 countries, GUF accounts for 50 percent or more of total government R&D to universities and for roughly 40 percent of the Canadian government academic R&D support. Thus, these data indicate not only relative international funding priorities but also funding mechanisms and philosophies regarding the best methods for financing research.

[61]In international S&E field compilations, the natural sciences comprise math and computer sciences, physical sciences, environmental sciences, and all life sciences other than medical and agricultural sciences. Also note that the U.S. academic R&D effort is considerably larger than in any other country and the U.S. total ($25 billion PPP) is comparable with the combined R&D total ($29 billion PPP) of the other seven countries listed in text table 4-15.

Text table 4-15.
Shares of academic R&D expenditures, by country and S&E field: 1998
(Percentages)

Field	United States	Japan	Germany	Australia	South Korea	Spain	Sweden	Russia
Total academic R&D (billions of 1995 PPP dollars)	24.8	13.4	7.3	2.0	1.8	1.8	1.4	1.4
Percent of total academic R&D								
Natural science and engineering	92.7	66.1	78.5	73.0	91.5	77.9	81.7	88.3
Natural sciences	41.0	11.5	30.3	27.5	18.5	40.8	22.3	59.0
Engineering	15.6	24.4	20.5	16.2	49.0	18.0	23.6	26.7
Medical sciences	28.6	25.5	23.3	22.8	17.0	13.9	29.0	1.7
Agricultural sciences	7.6	4.6	4.4	6.6	7.0	5.2	6.7	0.9
Social sciences and humanities	7.3	33.9	21.5	27.0	8.5	22.1	18.3	11.7
Social sciences	6.0	NA	8.6	19.5	NA	14.2	12.2	6.6
Humanities	1.3	NA	12.9	7.6	NA	7.8	6.1	5.1
Percent of academic NS&E R&D								
Natural science and engineering	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Natural sciences	44.2	17.4	38.6	37.7	20.2	52.4	27.3	66.8
Engineering	16.8	37.0	26.1	22.1	53.6	23.1	28.9	30.2
Medical sciences	30.8	38.6	29.6	31.2	18.6	17.8	35.5	1.9
Agricultural sciences	8.2	7.0	5.6	9.0	7.6	6.6	8.3	1.1

PPP = purchasing power parity; NA = detail not available, but included in totals

NOTES: These are the only OECD countries that report more than $1 billion (1995 PPPs) in higher education R&D and that provide S&E field data. Data for Sweden are for 1997.

SOURCES: Organisation for Economic Co-operation and Development (OECD), Main Science and Technology Indicators database (April 2001); Centre for Science Research and Statistics (CSRS), *Russian Science and Technology at a Glance: 2000* (Moscow, 2001); and National Science Foundation, Division of Science Resources Statistics (NSF/SRS).

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sites of R&D activity (e.g., food processing firms generally conduct less R&D than pharmaceutical firms), and on whether individual firms in the same industries devote substantial resources to R&D or emphasize other activities (i.e., firm-specific intensities). Text table 4-16 provides the distribution of industrial R&D performance in the G-8 countries and in Sweden and Finland, which have the first and third highest R&D/GDP ratios in the world, respectively.[62]

The level of industrial R&D in the United States far exceeds the level reported for any and all other of these countries, and therefore, the data are reported as shares of countries' industrial R&D totals. Most of these countries perform R&D in support of a large number of industry sectors. The sector distribution of the U.S. industrial R&D effort, however, is among the most widespread and diverse. This perhaps indicates a national inclination and ability to invest in becoming globally competitive in numerous industries rather than specializing in just a few industries or niche technologies. No U.S. industry sector accounts for more than 13 percent of the industry R&D total (the electrical equipment industry representing the highest level), and only two others (office machinery, including computers, and aerospace) account for 10 percent or more of the industry total. By comparison, most of the other countries display somewhat higher sector concentrations, including 20 percent or higher industry R&D shares for electrical equipment firms in Finland (at 44 percent of its industry total), Canada, Italy, and Sweden. Indeed, the electrical equipment sector is among the largest performers of the industrial R&D effort in 8 of the 10 countries shown (exceptions are the United Kingdom and Russia). Among other manufacturing sectors, 20 percent or higher shares are reported for motor vehicles in Germany and for pharmaceuticals in the United Kingdom, which is consistent with general economic production patterns.[63]

As indicated earlier, one of the more significant trends in U.S. industrial R&D activity has been the growth of the R&D effort within the nonmanufacturing sector. According to the internationally harmonized data in text table 4-16, such growth accounted for 20 percent of the U.S. 1997 industry R&D total, with computer services, R&D services, and trade each accounting for the largest individual shares (about 5 percent). A number of other countries also report substantial increases in their service sector R&D expenditures during the past 25 years. Among G-7 countries, nonmanufacturing R&D shares have increased by about 5 percentage points in France and Italy and by 13 percentage points in the United States, United Kingdom, and Canada since the early 1980s (Jankowski 2001b). In each of these three English-speaking countries, computer and related services account for a substantial share of the service R&D totals. Furthermore, R&D services appear to be an important locus of industry activity in several countries, reflecting in part the growth in outsourcing and

[62] Similar industrial R&D details for Switzerland and South Korea (which report the fourth and sixth highest R&D/GDP ratios in the world, respectively) were not available from OECD harmonized databases (OECD 2000a).

[63] See OECD (1999a) for a harmonized historical series on industry R&D expenditures in several OECD countries.

Text table 4-16.
Shares of industrial R&D, by industry sector for selected countries
(Percentages)

Industry	United States (1997)	Canada (1998)	Germany (1997)	France (1997)	Italy (1998)	Japan (1997)	United Kingdom (1998)	Russian Federation (1997)	Sweden (1997)	Finland (1998)
Total (billions of PPP dollars)	157.5	7.6	28.2	16.6	6.7	66.1	15.5	5.7	5.1	2.2
					Percent of total					
Total business enterprise	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Total manufacturing	79.9	63.8	93.5	87.3	85.6	92.6	80.5	36.8	85.9	87.2
Food, beverages, and tobacco	1.2	1.1	0.7	1.8	1.3	2.5	2.4	0.1	1.0	2.1
Textiles, fur, and leather	0.3	0.7	0.7	0.6	0.4	0.7	0.3	0.1	0.1	0.6
Wood, paper, printing, and publishing	1.4	1.6	0.4	0.4	0.3	1.1	0.5	0.2	3.4	4.2
Coke, ref. petroleum products, and nuclear fuel	1.1	1.2	0.3	1.4	0.6	0.6	3.5	0.5	0.2	0.6
Chemicals (less pharmaceuticals)	4.6	2.3	12.2	6.3	5.5	8.9	6.7	1.8	1.3	4.3
Pharmaceuticals	7.6	6.8	6.5	12.8	8.3	5.9	21.9	0.2	15.2	3.4
Rubber and plastic products	0.9	0.6	1.7	2.7	1.8	2.4	0.6	0.3	0.9	2.1
Nonmetallic mineral products	0.4	0.1	0.9	1.2	0.3	2.0	0.5	0.2	0.5	0.8
Basic metals	0.6	1.8	1.0	1.7	1.1	3.5	0.7	1.1	1.0	1.2
Fabricated metal products	1.2	1.0	1.5	1.2	4.4	1.2	0.9	0.2	1.1	1.9
Machinery, NEC	3.7	2.2	11.0	4.5	5.7	8.6	6.3	11.9	9.8	10.4
Office, accounting and computing machinery	11.6	4.0	2.3	2.4	1.8	9.7	1.2	0.0	0.8	0.7
Electrical machinery	2.9	0.9	3.0	3.6	5.5	10.5	4.1	1.3	1.5	5.2
Electronic equipment (radio, TV, and communications)	13.0	25.1	11.3	11.8	19.9	16.3	7.5	3.2	21.9	43.6
Instruments, watches, and clocks	8.8	1.2	5.2	9.9	1.7	3.9	3.3	0.8	5.2	3.5
Motor vehicles	9.6	1.6	24.2	12.1	15.3	12.8	8.9	3.2	18.2	0.5
Other transport equipment (less aerospace)	0.3	0.1	1.6	0.6	1.5	0.4	0.7	3.0	0.5	1.5
Aerospace	10.3	10.8	8.5	11.5	9.9	1.0	10.2	8.7	3.1	0.0
Furniture, other manufacturing NEC	NA	0.7	0.5	0.6	0.4	0.8	0.2	0.0	0.2	0.6
Recycling	0.3	NA	0.0	0.0	0.0	NA	0.0	0.0	NA	0.1
Electricity, gas, and water	0.2	2.7	0.3	3.0	1.7	0.9	1.4	0.5	0.8	1.6
Construction	0.2	0.3	0.3	1.0	0.3	2.1	0.4	0.9	0.6	0.8
Agriculture and mining	0.1	2.9	0.5	1.8	0.0	0.0	1.4	3.3	1.1	0.7
Total services	19.7	30.3	5.4	7.0	12.3	4.4	16.4	58.5	11.6	9.8
Wholesale, retail trade, motor vehicle repair, etc.	5.2	7.2	0.1	NA	0.4	NA	0.1	0.0	NA	0.1
Hotels and restaurants	0.1	NA	NA	NA	0.0	NA	NA	0.0	NA	NA
Transport and storage	0.4	0.1	0.2	2.8	0.1	0.1	0.2	0.5	0.3	0.2
Communications	1.3	1.3	NA	NA	0.7	2.7	4.4	0.7	2.3	5.4
Financial intermediation (incl. insur.)	1.0	2.8	0.0	NA	0.8	NA	NA	0.0	NA	NA
Computer and related activities	5.6	6.9	1.7	2.4	2.2	1.6	6.7	1.1	3.2	3.0
Research and development	4.5	9.5	1.4	NA	5.8	NA	3.4	44.9	5.2	NA
Other business activities NEC	NA	2.5	1.4	1.8	2.0	NA	1.5	0.4	0.5	0.8
Community, social and personal service activities, etc.	NA	NA	0.1	NA	0.2	NA	0.1	10.9	0.1	0.3

PPP = purchasing power parity; NA = not available separately; NEC = not elsewhere classified

NOTE: Analytical Business Enterprise Research and Development (ANBERD) data not available for Switzerland and South Korea. Data are for the years listed under country names.

SOURCES: Organisation for Economic Co-operation and Development (OECD), Analytical Business Enterprise Research and Development (ANBERD) database (DSTI/EAS Division), (Paris, 2000); and OECD, *R&D Efforts in China, Israel, and Russia: Some Comparisons With OECD Countries* (CCNM/DSTI/EAS, Paris, 2000).

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greater reliance on contract R&D in lieu of in-house performance, as well as intramural R&D in these industries.

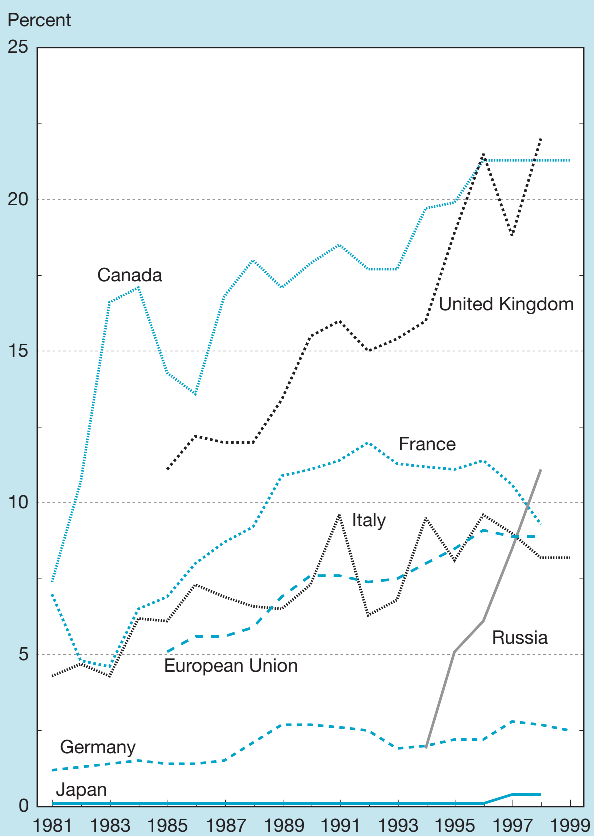
According to the national statistics, only in Germany and Japan do the nonmanufacturing sectors currently account for less than 10 percent of the industry R&D performance total. Among the countries listed in text table 4-16, services R&D shares range from as little as 4 percent in Japan to 59 percent in Russia. The latter figure, however, primarily occurs because specialized industrial research institutes perform a large portion of Russia's industry and federal government R&D and are classified under the "research and development" sector within the service sector. Apart from these institutes, the manufacturing-nonmanufacturing split in Russia's industrial R&D would be similar to ratios in the United States (American Association for the Advancement of Science (AAAS) and Centre for Science Research and Statistics (CSRS) 2001).

Source of Funds. Most of the industrial R&D in each of these eight countries is provided by industry itself. As is the situation for OECD countries overall, government financing accounts for a small and declining share of the industry R&D performance total within G-7 countries. See "Government Sector" for further discussion. Government financing shares range from as little as 2 percent of the industry R&D in Japan to 13 percent of Italy's industry R&D effort. (See appendix table 4-42.) (For recent historical reasons, Russia is the exception to this pattern among the G-8 countries, with government accounting for 43 percent of its industry total.) In the United States, the Federal Government currently provides about 11 percent of the R&D funds used by industry, and the majority of that funding is obtained through contracts from DOD.

As shown in figure 4-31, funds from abroad accounted for as little as 0.4 percent of Japan's R&D expenditure total to almost 22 percent of total R&D expenditures in the United Kingdom. Foreign funding, predominantly from industry for R&D performed by industry but also including some small amounts of foreign funding provided to other nonindustry sectors, is an important and growing funding source in several countries. Growth in this funding source primarily reflects the increasing globalization of industrial R&D activities overall. For European countries, however, the growth in foreign sources of R&D funds may also reflect the expansion of coordinated European Community (EC) efforts to foster cooperative shared-cost research through its European Framework Programmes.[64] Although the growth pattern of foreign funding has seldom been smooth, it now accounts for more than 20 percent of industry's domestic performance totals in Canada and the United Kingdom and approximately 10 percent of industry R&D performed in Italy, France, and Russia. (See figure 4-31.) Such funding takes on even greater importance in many of the smaller OECD countries as well as in less industrialized countries (OECD 1999b).

In the United States, approximately 13 percent of funds spent on industry R&D performance in 1998 are estimated to have come from majority-owned affiliates of foreign firms investing domestically. This amount was considerably more than the 3 percent funding share provided by foreign firms in 1980 and their 8 percent share reported as recently as 1991.[65]

Figure 4-31.
Proportion of industrial R&D financed by foreign sources



See appendix table 4-45.

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Government Sector

Government R&D Funding Totals. In most countries, the government sector makes its strongest impact on the R&D enterprise not by conducting R&D but, rather, by financing R&D. The government sector accounts for only 11 percent of OECD members' combined R&D performance in 1998 (OECD 2000a) and for 26 percent or (usually much) less in each of the G-8 countries. (See appendix table 4-42.) Government accounted for 13 percent of the OECD performance total as recently as 1995.

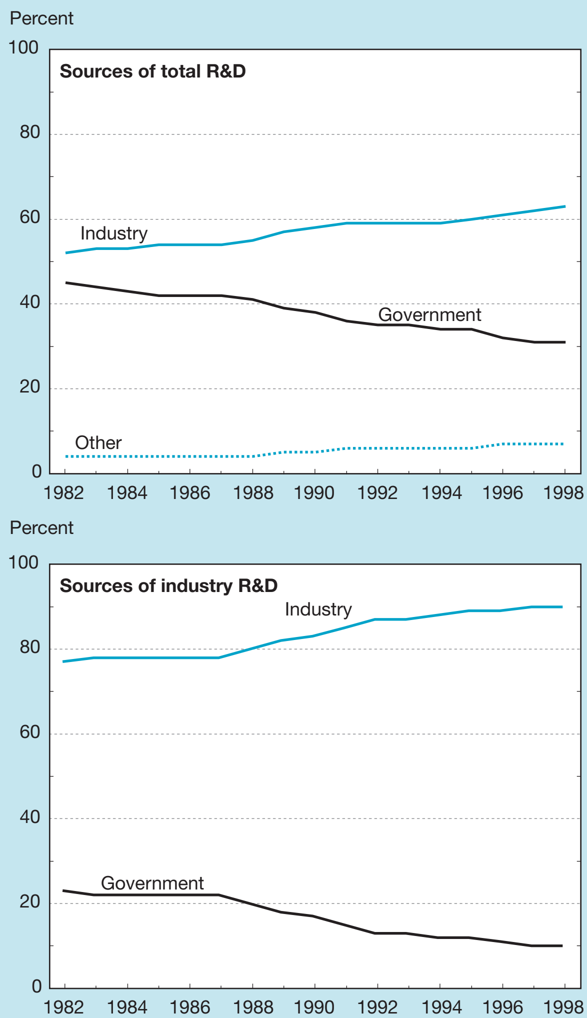
The decline in governments' share of the R&D performance totals, however, pales in comparison with their shrinking share of the R&D financing total. Indeed, the most significant trend among the G-7 and other OECD countries has been the relative decline in government R&D funding in the 1990s. In 1998, less than one-third of all R&D funds were derived from government sources, down considerably from the 45 percent share reported 16 years earlier. (See figure 4-32.) Among all OECD countries, government accounts for the highest funding share in Portugal (68 percent

[64]Since the mid-1980s, EC funding of R&D has become increasingly concentrated in its multinational Framework Programmes for Research and Technological Development (RTD), which were intended to strengthen the scientific and technological bases of community industry and to encourage it to become more internationally competitive. EC funds distributed to member countries' firms and universities have grown considerably. The EC budget for RTD activities has grown steadily from 3.7 billion European Currency Units (ECU) in the First Framework Programme (1984–87) to an estimated 15 billion ECU for the Fifth Framework Programme that runs from 1998 to 2002. The institutional recipients of these would tend to report the source as "foreign" or " funds from abroad" (Eurostat 2001).

[65]Unlike for other countries, there are no data on foreign sources of U.S. R&D performance. The figures used here to approximate foreign involvement are derived from the estimated percentage of U.S. industrial performance undertaken by majority-owned (i.e., 50 percent or more) nonbank U.S. affiliates of foreign companies. In short, the U.S. foreign R&D totals represent industry funding based on foreign ownership regardless of originating source, whereas the foreign totals for other countries represent flows of foreign funds from outside the country to any of its domestic performers. See the extensive coverage of industrial foreign R&D investments in the following sections of this chapter.

of its 1997 R&D total) and the lowest share in Japan (19 percent in 1998). Part of the relative decline reflects the effects of budgetary constraints, economic pressures, and changing priorities in government funding (especially the relative reduction in defense R&D in several of the major R&D-performing countries, notably France, the United Kingdom, and the United States). Another part reflects the absolute growth in industrial R&D funding as a response to increasing international competitive pressures in the marketplace, irrespective of government R&D spending patterns, thereby increasing the relative share of industry's funding as compared with government's funding. Both of these considerations are reflected in funding patterns for industrial R&D performance alone. In 1982, government provided 23 percent of the funds used by industry in conducting R&D within OECD countries, whereas by 1998 government's share of the industry R&D total had fallen by more than half, to 10 percent of the total. In most OECD countries (as in the United States), government support for business R&D is skewed toward large firms.

Figure 4-32.
Sources of R&D expenditures in OECD countries



OECD = Organisation for Economic Co-operation and Development

See appendix table 4-44.

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Government R&D Priorities. A breakdown of public expenditures by major socioeconomic objectives provides insight into government priorities that as a group have changed over time and that individually differ considerably across countries.[66] Within OECD, the defense share of governments' R&D financing total has declined annually since the mid-1980s. Accounting for 44 percent of the government total in 1986, defense-related activities now garner a much smaller 31 percent share. (See text table 4-17.) Much of this decline is driven by the U.S. experience: 53 percent of the U.S. Government's $78 billion R&D investment during 1999 was devoted to national defense, down from its 69 percent share in 1986. Nonetheless, defense still accounts for a relatively larger government R&D share in the United States than elsewhere. This share compares with the 35 percent defense share in the United Kingdom (of a $9 billion government total), 30 percent in Russia (of $4 billion), 23 percent in France (of $13 billion), and less than 10 percent each in Germany, Italy, Canada, and Japan. (See figure 4-33 and appendix table 4-43.) As in the United States, these recent figures represent substantial cutbacks in defense R&D in the United Kingdom and France, where defense accounted for 44 and 40 percent, respectively, of government R&D funding in 1990. However, defense-related R&D also seems particularly difficult to account for in many countries' national statistics. See sidebar, "Tracking R&D: Gap Between Performer- and Source-Reported Expenditures."

Concurrent with the changes in overall defense/nondefense R&D shares, notable shifts have occurred in the composition of OECD countries' governmental nondefense R&D support during the past two decades. In terms of the broad socioeconomic objectives to which government programs are classified in various international reports (OECD 1999a, 2000f), government R&D shares have increased most for health and the environment and for various nondirected R&D activities (identified in text table 4-17 as "other purposes").[67] Growth in health-related R&D financing has been particularly strong in the United States, whereas many of the other OECD countries have reported relatively greater growth for environmen-

[66]Data on the socioeconomic objectives of R&D funding are rarely obtained by special surveys; they are generally extracted in some way from national budgets. Because those budgets already have their own methodology and terminology, these R&D funding data are subject to comparability constraints not placed on other types of international R&D data sets. Notably, although each country adheres to the same criteria for distributing their R&D by objective as outlined in OECD's *Frascati Manual* (OECD 1994), the actual classification may differ among countries because of differences in the primary objective of the various funding agents. Note also that these data reflect government R&D funds only, which account for widely divergent shares and absolute amounts of each country's R&D total.

[67]Health and environment programs include human health, social development, protection of the environment, and exploration and exploitation of the Earth and its atmosphere. R&D for "other purposes" in text table 4-17 includes nonoriented programs, advancement of research, and primarily GUF (e.g., the estimated R&D content of block grants to universities described in note 56).

Text table 4-17.
Government R&D support for defense and nondefense purposes, all OECD countries
(Percentages)

Year	Government R&D budget shares: Defense	Government R&D budget shares: Nondefense	Government nondefense R&D budget shares: Health and environment	Economic development programs	Civil space	Other purposes
1981	35.6	64.4	19.7	37.5	9.9	32.9
1982	38.1	61.9	19.4	37.7	8.6	34.3
1983	39.9	60.1	19.3	36.8	7.7	36.2
1984	41.8	58.2	20.1	35.9	7.9	36.1
1985	43.4	56.6	20.5	35.6	8.6	35.3
1986	44.4	55.6	20.5	34.5	8.8	36.2
1987	44.1	55.9	21.2	32.3	9.8	36.7
1988	43.4	56.6	21.5	30.7	10.2	37.6
1989	42.0	58.0	21.8	29.9	11.0	37.3
1990	40.2	59.8	22.3	29.0	12.1	36.6
1991	37.3	62.7	22.3	28.6	12.2	36.9
1992	36.0	64.0	22.6	27.5	12.3	37.6
1993	36.0	64.0	22.5	26.6	12.5	38.4
1994	33.5	66.5	22.7	25.6	12.6	39.1
1995	31.6	68.4	22.7	24.6	12.3	40.4
1996	31.3	68.7	22.8	24.5	12.0	40.7
1997	31.3	68.7	23.1	24.7	11.6	40.6
1998	30.5	69.5	23.9	22.7	11.5	41.9

SOURCE: Organisation for Economic Co-operation and Development (OECD), Main Science and Technology Indicators database (Paris, November 2000).

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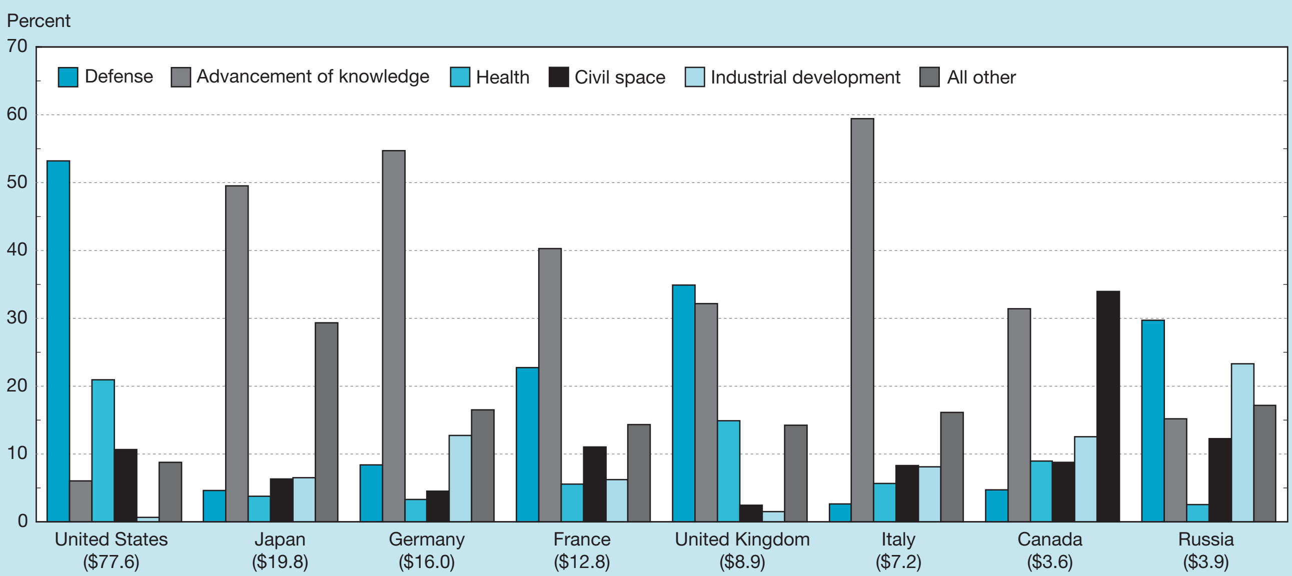
Figure 4-33.
Government R&D support by socioeconomic objectives, G-8 countries



NOTES: The amounts listed under country names represent total government R&D support in billions of U.S. purchasing power parity (PPP) dollars. Data for Italy, Russia, and Canada are for 1998; data for all other countries are for 1999. R&D is classified according to its primary government objective, although it may support any number of complementary goals. For example, defense R&D with commercial spinoffs is classified as supporting defense, not industrial development. R&D for the advancement of knowledge is not equivalent to basic research.

See appendix table 4-43.

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Tracking R&D: Gap Between Performer- and Source-Reported Expenditures

In many OECD countries, including the United States, total government R&D support figures reported by government agencies differ substantially from those reported by performers of R&D work. Consistent with international guidance and standards (OECD 1994), however, most countries' national R&D expenditure totals and time series are based primarily on data reported by performers. This convention is preferred because performers are in the best position to indicate how much they spent in the actual conduct of R&D in a given year and to identify the source of their funds. Although funding and performing series may be expected to differ for many reasons such as different bases used for reporting government obligations (fiscal year) and performance expenditures (calendar year), the gap between the two R&D series has widened during the past several years. Additionally, the divergence in the series is most pronounced in countries with relatively large defense R&D expenditures (National Science Board (NSB) 1998).

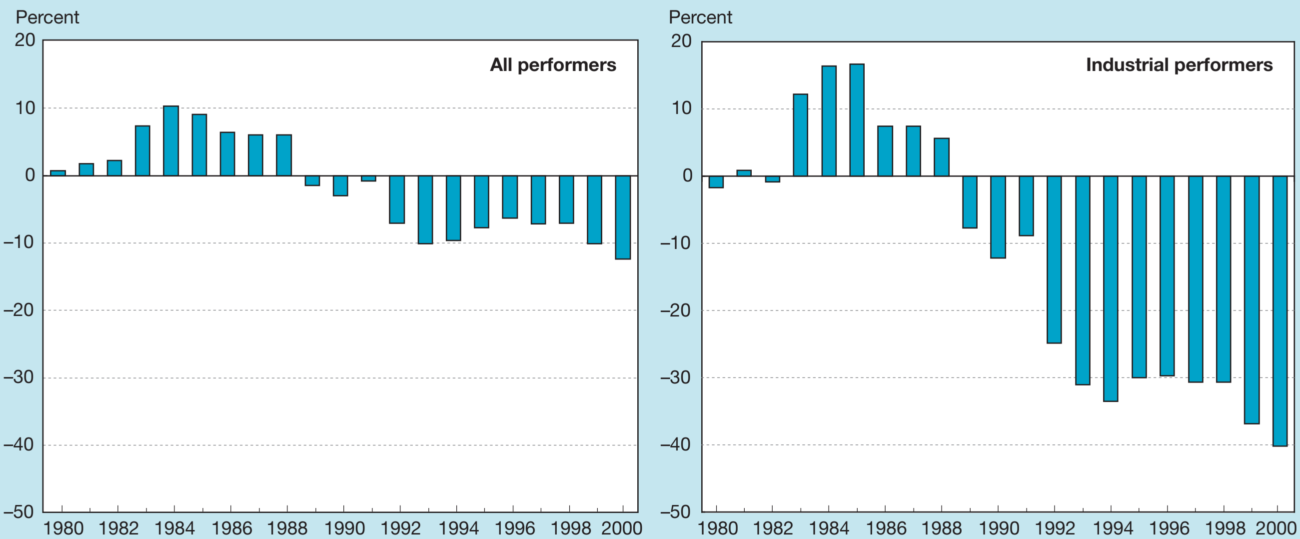
Data Gap Trends

For the United States, the reporting gap has become particularly acute over the past several years. In the mid-1980s, performer-reported Federal R&D exceeded Federal reports by \$3 to \$4 billion annually (5–10 percent of the government total). This pattern reversed itself toward the end of the decade; in 1989, the government-reported R&D total exceeded performer reports by \$1 billion. The gap has since grown to about \$8 billion. In other words, approximately 10 percent of the government total in 1999 is unaccounted for in performer surveys. (See figure 4-34.) The difference in Federal R&D totals is primarily in Department of Defense (DOD) development funding of industry (principally aircraft and missile firms). For 1999, Federal agencies reported \$31.9 billion in total R&D obligations provided to industrial performers compared with an estimated \$20.2 billion in Federal funding reported by industrial performers. (DOD reports industry R&D funding of \$24.6 billion, whereas industry reports using \$11.7 billion of DOD's R&D funds.) Overall, industrywide estimates equal a 37 percent paper "loss" of federally reported 1999 R&D support. (See figure 4-34.)

Reasons for Data Gaps

Interviews with industry representatives have helped the National Science Foundation (NSF) identify possible reasons that performer-reported R&D totals might differ from funding agency-reported totals. Generally, since the end of the cold war, numerous changes have occurred in the defense contracting environment and DOD's budgeting process. These have been accompanied by major shifts in the composition of R&D, test, and evaluation contracts, which may account for some of the statistical discrepancies. In ways unknown a decade earlier, new types of defense contractors and nontraditional forms of R&D expenditures apparently play a major role in complicating the collection of R&D data. (A complete summary of the NSF study appeared in NSB 2000.)

Figure 4-34.
Difference in U.S. performer-reported versus agency-reported Federal R&D



NOTE: Difference is defined as percentage of federally reported R&D.

See appendix table 4-34.

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More recently, however, Federal agencies and representatives from firms and universities (recipients of Federal R&D funding) gathered at a Congressional Research Service (CRS) workshop to discuss these R&D data issues. Not surprisingly, participants were unable to reach a consensus on the reasons for the growing data gaps. According to the CRS summary (Davey and Rowberg 2000), participants generally agreed that agency downsizing in recent years has left fewer resources to collect, process, and report R&D data to NSF. Because agencies do not place a high priority on such data reporting, those who report data are likely to be the early victims of downsizing. Nonetheless, the agencies with the largest discrepancy between their reported R&D obligations and the R&D expenditures reported by industry performers receiving those funds (DOD, Department of Energy, and National Aeronautics and Space Administration) believe that the source of the discrepancy lies almost exclusively with the performers. Those agencies have reviewed their data collection and reporting methods and contend that they have been stable and consistent over the period during which the discrepancies have grown.

On the other hand, the U.S. Bureau of the Census, which collects the industry R&D data for NSF, stated that it has not seen any significant shifts in the character of that data since at least 1992. In particular, no significant changes have appeared that could correlate with the rise in mergers and acquisitions among the surveyed firms. Industry participants questioned why agencies were not solely responsible for reporting these Federal R&D funding data to NSF rather than sharing the burden with industry. And according to an even more recent U.S. General Accounting Office (2001a) investigation, "Because the gap is the result of comparing two dissimilar types of financial data [Federal obligations and performer expenditures], it does not necessarily reflect poor quality data, nor does it reflect whether performers are receiving or spending all the Federal R&D funds obligated to them. Thus, even if the data collection and reporting issues were addressed, a gap would still exist." In summary, users should expect no quick resolution to the issue of why performer-reported R&D data differ from the data reported by the funding Federal agencies, nor perhaps should they be overly concerned about the discrepancy.

tal research programs. Indeed, as is indicated from a variety of R&D metrics, the emphasis on health-related research is much more pronounced in the United States than in other countries, although the importance of tracking the R&D contribution to improving human health has become widely accepted (OECD 2001a). In 1999, the Federal Government devoted 21 percent of its R&D investment to health-related R&D, making such activities second only to defense. (Direct comparisons between health and defense R&D are complicated because most of the health-related R&D is research, and about 90 percent of defense R&D is development.)

The relative shift in emphasizing nondirected R&D reflects government priority setting during a period of fiscal austerity and constraint. With fewer discretionary funds available to support R&D, governments have tended to conduct activities that are traditionally in the government sphere of responsibility and for which private funding is less likely to be available. For example, basic research projects are inextricably linked to higher education.[68] Conversely, the relative share of government R&D support provided for economic development programs has declined considerably, from 38 percent of total in 1981 to 23 percent in 1999. Economic development programs include the promotion of agriculture, fisheries and forestry, industry, infrastructure, and energy, all activities for which privately financed R&D is more likely to be provided without public support, although the focus of such private and public support would undoubtedly differ somewhat.

Different activities are emphasized in individual countries' governmental R&D support statistics. Japan committed 19 percent of its total governmental R&D support ($20 billion) to energy-related activities, reflecting the country's historical concern about its high dependence on foreign sources of energy. (See appendix table 4-43.) In Canada, 11 percent of the government's $4 billion in R&D funding was directed toward agriculture. Space R&D received considerable support in the United States and France (11 percent of the total in each country), while industrial development accounted for 8 percent or more of governmental R&D funding in Canada, Germany, Italy, and Russia. In fact, industrial development is the leading socioeconomic objective for R&D in Russia, accounting for 23 percent of all government R&D, funding for which is primarily oriented toward the development of science-intensive industries and is aimed at increasing economic efficiency and technological capabilities (AAAS and CSRS 2001).[69] Industrial development programs accounted for 7 percent of the Japanese total but for less than 1 percent of U.S. R&D. (See figure 4-33.) The latter figure, which includes mostly R&D funding by NIST of the U.S. Department of Commerce, is understated relative to most other countries as a result of data compilation differences. In part, the low U.S. industrial development share reflects the expectation that firms will finance industrial R&D activities with their own funds; in part, government R&D that may be indirectly useful to in-

[68]See Kaiser et al. (1999) for a description on recent efforts to make higher education R&D data more internationally comparable.

[69]As an added indication of evolving government priorities in Russia, fully 27 percent of the government's 1998 R&D budget appropriations for economic programs were used to assist in the conversion of the country's defense industry to civil applications (AAAS and CSRS 2001).

dustry is often funded with other purposes in mind such as defense and space (and is therefore classified under other socioeconomic objectives).

Japanese, German, and Italian government R&D appropriations in 1998–99 were invested relatively heavily in advancement of knowledge (50 percent or more of the $20 billion total for Japan, 55 percent of Germany's $16 billion total, and 59 percent of the $7 billion total in Italy). "Advancement of knowledge" is the combined support for advancement of research and GUF.[70] Indeed, the GUF component of advancement of knowledge, for which there is no comparable counterpart in the United States, represents the largest part of government R&D expenditure in most OECD countries.

R&D Tax Policies. In many OECD countries, government not only provides direct financial support for R&D activities but also uses indirect mechanisms such as tax relief to promote national investment in S&T. Indeed, tax treatment of R&D in OECD countries is broadly similar, with some variations in the use of R&D tax credits (OECD 1996, 1999a). The main features of the R&D tax instruments are as follows:

- Almost all OECD countries (including the United States) allow 100 percent of industry R&D expenditures to be deducted from taxable income in the year they are incurred.
- About one-half of OECD countries (including the United States) provide some type of additional R&D tax credit or incentive with a trend toward using incremental credits. A few countries also use more targeted approaches, such as those favoring basic research.
- Several OECD countries have special provisions that favor R&D in small and medium-size enterprises. (In the United States, credit provisions do not vary by firm size, but direct Federal R&D support is provided through grants to small firms.)

A growing number of R&D tax incentives are being offered in OECD countries at the subnational (provincial and state) levels, including in the United States. See Poterba (1997) for a discussion of international elements of corporate R&D tax policies.

International Industrial R&D Investments

International R&D investments refer to R&D and related long-term activities by private companies outside of the home country. Broadly speaking, these activities include the acquisition or establishment of R&D facilities abroad, R&D spending in foreign subsidiaries (in manufacturing, services, or research facilities), international R&D alliances, licensing agreements, and contract research overseas. These activities fulfill different objectives in corporate R&D strategies and exhibit various degrees of managerial and financial commitment from the parties involved. Although public data on these international business activities are key for S&T policy analysis and design, their availability varies considerably, even within advanced economies.

In this section, the focus is on R&D spending trends to and from the United States, with a brief overview of overseas and foreign-owned domestic R&D facilities.[71] In principle, trends in R&D facilities are tied to overall foreign direct investment (FDI) trends, especially in high-technology industries. However, comprehensive FDI data on acquired and established facilities by type of major activity (i.e., manufacturing versus research) are not available in most countries.[72] On the other hand, R&D spending by multinational corporations are readily available from financial and operating data collected in FDI statistics.

By definition, R&D spending in subsidiaries abroad is preceded by the acquisition or establishment of foreign facilities. More fundamentally, however, the economics of these two activities have become increasingly intertwined in advanced economies. For one, FDI flows are becoming a key element in understanding the overall corporate R&D strategy of global companies. Conversely, knowledge-based assets are becoming an increasingly important factor in FDI decisions by multinational companies. However, empirical links are elusive with the available data. For example, mere changes in ownership can affect R&D spending statistics without representing changes in the actual performance of R&D domestically.

Foreign Direct Investments and R&D Facilities

Total foreign direct investments have increased steadily in recent years in the United States and elsewhere, according to data from the Bureau of Economic Analysis (BEA). Recent increases worldwide have been fueled by motives ranging from market liberalization efforts leading to privatization drives in some emerging markets, proximity to existing or potential large consumer markets, and regional technological advantages. Foreign direct investment flows into the United States are dominated by the lure of a large domestic market and by the technological sophistication of many of its firms. Technology-related factors driving FDI include an educated and skilled workforce, a favorable regulatory environment, and the need for complementary technologies in an increasingly complex and rapid innovation process.

According to an OECD study, as much as 85 percent of FDI activity worldwide consists of mergers and acquisitions (M&As), compared to the establishment of new industrial facilities or so-called greenfield investments (Kang and Johansson

[70] In the United States, "advancement of knowledge" is a budgetary category for research unrelated to a specific national objective. Furthermore, although GUF are reported separately for Japan, Canada, and European countries, the United States and Russia do not have an equivalent GUF category. In the United States, funds to the university sector are distributed to address the objectives of the Federal agencies that provide the R&D funds. GUF is not equivalent to basic research. For 1999, the GUF portion of total national governmental R&D support was 48 percent in Italy, 39 percent in Germany, 37 percent in Japan, and between 18 and 24 percent in the United Kingdom, Canada, and France.

[71] Data limitations preclude the inclusion of contract R&D with (or grants to) foreign organizations, whereas international technology alliances are discussed earlier in this chapter.

[72] As discussed below, a DOC survey with 1997 and 1998 data provides the latest available indicators of overseas and foreign-owned domestic R&D facilities.

2000). M&As involving high-technology facilities supply not only vital research infrastructure (such as specialized facilities and equipment) but also an existing base of intangible assets key in the development and marketing of new technologies including technical know-how and skilled workers, organizational knowledge, marketing networks, and trademarks.

In the United States, data on foreign-owned research facilities are available only to 1998 from a DOC survey (Dalton, Serapio, and Yoshida 1999). In 1998, 715 U.S. R&D facilities were operated by 375 foreign-owned companies, including 251 facilities (35 percent) owned by Japanese parent companies. Other countries with a major presence were Germany 107 (15 percent) and the United Kingdom 103 (14 percent). One-third of the facilities were chemicals/rubber, drugs, and biotechnology centers, most with German, Japanese, or British parent companies. Another 10 percent (74) were computer and semiconductor R&D facilities, and 7 percent (53) conducted software research. Almost two-thirds of these computer and software research centers were Japanese owned, with a good share located in California. On the other hand, by 1997 U.S. companies had established at least 186 R&D facilities overseas. Two-thirds of these facilities were located in five countries: Japan (43), United Kingdom (27), Canada (26), France (16), and Germany (15).[73]

Foreign R&D and R&D Expenditure Balance

R&D spending by U.S. affiliates of foreign companies in the United States (or foreign R&D spending) increased 28 percent in 1997–98, from $17 billion to $22 billion, the largest single-year increase since 1990, as compiled by BEA (2000).[74] (See appendix table 4-50.) This pushed foreign R&D as a proportion of company-funded industrial R&D in the United States to a record 15 percent in 1998, after fluctuating around 13 percent since 1994. (See figure 4-35.)

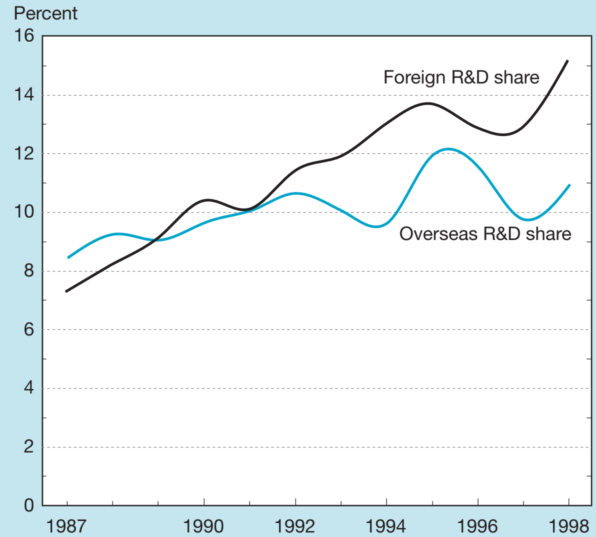
When combined with the $15 billion of R&D spent abroad by U.S.-based companies, this yields a "net inflow" of R&D expenditures of more than $7 billion in 1998 compared with $3 billion a year earlier.[75] (See figure 4-36.) However, this record increase in net U.S. inflows needs to be put in perspective. In particular, data on foreign R&D spending in the United States are affected by changes in ownership involving domestic and foreign companies, as in cross-country M&As. In 1998, two of the largest M&As included the Daimler-Benz (Germany) merger with Chrysler and the British Petroleum (United Kingdom) merger with Amoco. Acquisition of Ameri-

[73]For a detailed discussion of the results of the DOC survey, see NSB (2000), pages 2–65/66.

[74]Data are for R&D performed in the United States by majority-owned (more than 50 percent) nonbank U.S. affiliates of foreign parent companies. See appendix tables 4-50 and 4-51. Appendix table 4-49 has R&D spending data based on 10 percent foreign ownership. Data are based on the concept of an ultimate beneficial owner, which is the person "proceeding up the U.S. affiliate's ownership chain beginning with and including the foreign parent, that is not owned more than 50 percent by another person." For more details and definitions, see Quijano (1990).

[75]Note that the BEA data used here are based on R&D performance, not funding source (domestic or foreign). Still, these R&D spending trends do provide an indication of the industrial and R&D strategies of multinational companies based in, or with activities in, the United States.

Figure 4-35.
Ratio of foreign and overseas R&D spending to company-funded industrial R&D



NOTES: Foreign R&D refers to R&D performed in the United States by U.S. affiliates of foreign parent companies. Overseas R&D refers to R&D performed abroad by foreign affiliates of U.S. parent companies.

See appendix tables 4-32, 4-46, and 4-50.

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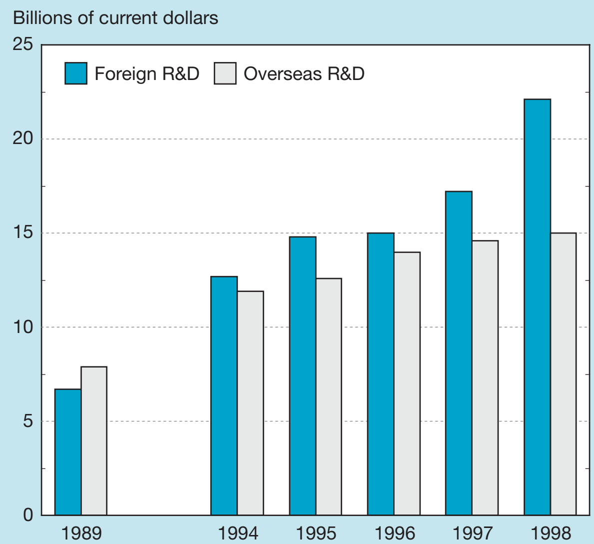
Figure 4-36.
Globalization of U.S. industrial R&D



NOTES: Foreign R&D refers to R&D performed in the United States by U.S. affiliates of foreign parent companies. Overseas R&D refers to R&D performed abroad by foreign affiliates of U.S. parent companies.

See appendix tables 4-48 and 4-50.

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can R&D-performing companies increases reported R&D funded by foreign affiliates that may or may not represent actual changes in research activities beyond a change in ownership. Difficulties in the valuation of purchased in-process R&D, the cumulative (and more difficult to track) effect of smaller acquisitions, and the offsetting effects of divestitures also make it difficult to assess the effect of cross-border M&A activity in international R&D spending flows.

Chemical manufacturing and the new NAICS sector of computer and electronic product manufacturing had the largest single-industry shares of foreign R&D in 1998 (33 and 20 percent, respectively). They include the largest subsectors attracting foreign R&D funding: pharmaceuticals and communications equipment (see appendix table 4-51). As detailed below, more than one-half of foreign-owned chemicals and pharmaceuticals R&D in the United States is performed by Swiss and German subsidiaries. Transportation equipment (mostly motor vehicles and bodies) had a 12 percent share in 1998, up sharply from the 1997 share, in part due to cross-border M&A activity. The most notable nonmanufacturing sectors are professional, scientific, and technical services (NAICS sector 54), which include R&D services, with a 3 percent share, and information services (NAICS sector 51), with 2 percent share. The latter includes such R&D-intensive industries as telecommunications and data processing services.

Comparable to statistics on high-technology trade and FDI flows, European, Japanese, and Canadian companies make the largest R&D investments in the United States. (See figure 4-37.) In 1998, American affiliates of European parent companies represented 72 percent of the $22 billion R&D spending in the United States, down slightly from 75 percent in 1996, Asia-Pacific (14.4 percent, including Japan at 11.7 percent), and Canada (10.7 percent). Among the European countries, the largest shares correspond to Germany (22.1 percent), the United Kingdom (16.7 percent), and Switzerland (14.0 percent).

Furthermore, specific countries dominate foreign majority-owned R&D expenditures in certain U.S. industries. Swiss subsidiaries performed 34 percent of foreign-owned R&D in chemicals as well as 26 percent of foreign-owned industrial machinery R&D in 1998. German subsidiaries performed 20 percent of foreign-owned chemical R&D. At the same time, more than 90 percent of R&D spending by foreign-owned transportation equipment affiliates is performed by European subsidiaries.[78] On the other hand, 25 percent of the Japanese-owned $2.6 billion R&D spending in the United States is performed in the area of computers and other electronic products. (See text table 4-18.)

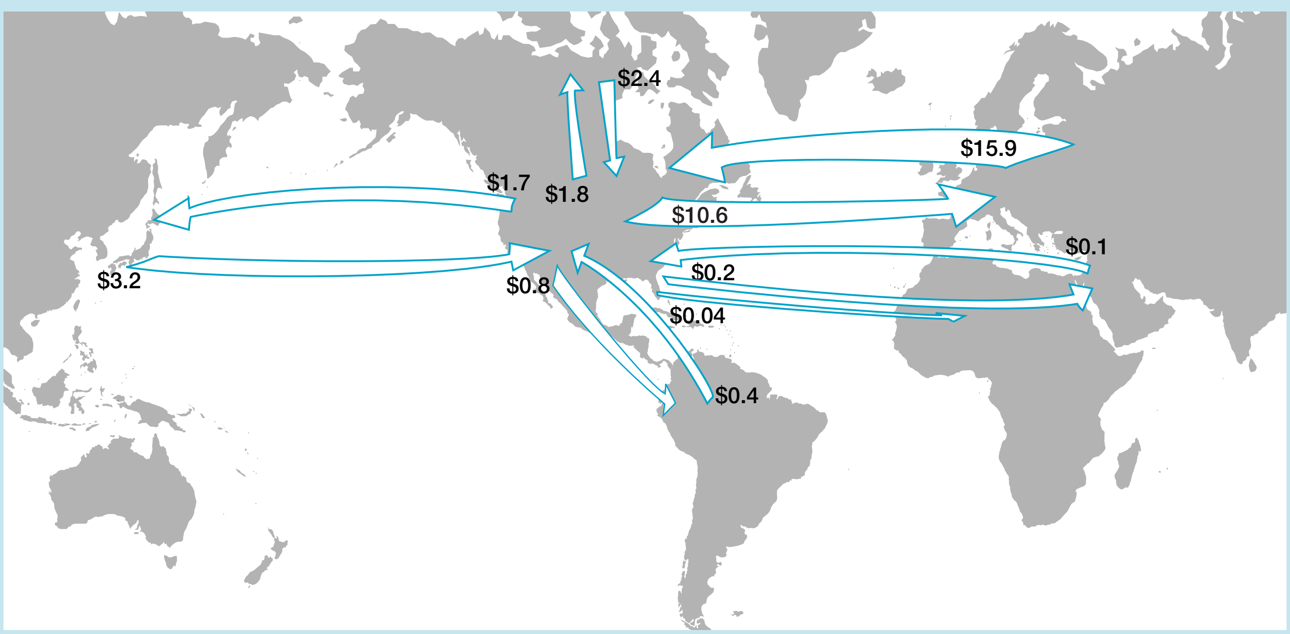
Overseas R&D Spending

According to data from the NSF Industrial R&D survey (NSF 2001e), R&D performed abroad by foreign affiliates of U.S. parent companies (or overseas R&D spending) reached

[78]Disclosure limitations preclude further country-specific analysis.

Figure 4-37.
Industrial R&D spending of U.S. and foreign affiliates, by world region: 1998

Billions of current dollars



See appendix tables 4-48 and 4-50.

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Text table 4-18.
R&D performed by majority-owned U.S. affiliates of foreign companies in the United States, by NAICS industry of affiliate and country: 1998
(Millions of U.S. dollars)

Country	All industries	Manufacturing Total	Chemicals	Machinery	Computers	Electrical equipment	Transportation equipment	Non-manufacturing
Total	22,073	18,256	7,193	725	4,509	898	2,678	3,817
Canada	2,353	2,127	12	5	D	D	D	226
Europe	15,904	14,197	6,749	D	D	D	2,416	1,707
France	1,905	1,807	712	3	535	123	88	98
Germany	4,880	4,570	1,387	D	77	D	D	310
Netherlands	985	941	359	D	D	1	D	44
Switzerland	3,083	2,956	2,443	189	28	3	0	127
United Kingdom	3,685	3,005	D	177	220	72	128	680
Asia and Pacific	3,180	1,600	408	D	664	D	224	1,580
Japan	2,578	1,470	D	D	637	7	171	1,108
Western hemisphere	393	D	—	0	5	0	8	D
Middle East	129	116	D	4	91	0	0	13
Africa	D	D	0	0	0	0	0	D

NAICS = North American Industry Classification System; D = withheld to avoid disclosing operations of individual companies; — = less than $500,000

NOTES: Data are for majority-owned (more than 50 percent ownership) non–bank affiliates of foreign parents by country of ultimate beneficial owner (UBO). Industry of affiliate based on NAICS industrial classification system. Data include expenditures for R&D conducted by affiliates, whether for themselves or for others under contract. Data exclude expenditures for R&D conducted by others for affiliates under contract. See also appendix tables 4-50 and 4-51.

SOURCE: U.S. Bureau of Economic Analysis, *Foreign Direct Investment in the United States: Operations of U.S. Affiliates of Foreign Companies,* Preliminary 1998 Estimates (Washington, DC, 2000).

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$17 billion in 1999. (See appendix table 4-47.)[79] In the three-year period for which NAICS-based data are available from this survey (1997 to 1999) this spending grew 28 percent (25 percent after adjusting for inflation).[80] Although the manufacturing share in R&D spending by American subsidiaries abroad declined from 90 percent in 1997 to 74 percent in 1999,[81] the largest single-industry shares in 1999 are all in this sector: transportation equipment (24 percent), chemicals (19 percent), pharmaceuticals, (17 percent), and computer and electronic products (11 percent). The nonmanufacturing information sector represented 8 percent of spending by foreign affiliates of American companies in 1999, up from a 5 percent share in 1997. Professional, scientific, and technical services had a 3 percent share in 1999 compared to 2 percent in 1998 and 1 percent in 1997.

Data on overseas R&D spending are available with country detail from a separate BEA survey but only through 1998. BEA data show that R&D expenditures overseas by majority-owned foreign affiliates (MOFAs) of U.S. multinationals increased from $12 billion in 1994 to $15 billion in 1998, for an annual growth rate of 4.8 percent.[82] The 1998 figure represents an increase of 2.7 percent over 1997 (1.4 percent after adjusting for inflation). However, this increase in R&D overseas did not keep pace with domestic industrial R&D, as shown in figure 4-35, where overseas R&D spending is presented relative to domestic company-funded industrial R&D.

More than two-thirds ($10.3 billion) of R&D performed overseas in 1998 took place in five countries: the United Kingdom, Germany, Canada, France, and Japan. (See appendix table 4-48.) This concentration of R&D spending abroad corresponds with other overseas activities by U.S. multinational companies. In particular, Mataloni (2000) notes an increase in new or acquired MOFAs by U.S. multinationals in large markets with high wages, especially to the United Kingdom, as opposed to low-wage countries. Not surprisingly, R&D expenditures by majority-owned foreign affiliates of U.S. parent companies were also the highest in the United Kingdom ($3 billion, or 21 percent of overseas R&D). Cultural and economic similarities with the United States, such as the low level of market regulation, as well as the duty-free access to customers in other European Union members, makes the United Kingdom a prime target for new MOFA operations.[83] In addition, advanced economies offer U.S. affiliates either large or high-income markets, and technological know-how

[79]The 1998 NSF figure for R&D abroad is $16 billion, higher than the BEA tally of $15 billion in 1998 discussed below. At the time this report was written, 1999 BEA data were not available.

[80]For historical data, see appendix table 4-46.

[81]Note that manufacturing shares for 1997–99 are not completely comparable with previous years based on the SIC system. For example, some of the new nonmanufacturing sectors in NAICS contain activities previously classified in manufacturing.

[82]In constant 1996 dollars, the annual growth rate was 3.3 percent, reaching $14.5 billion in 1998.

[83]U.S. MNCs acquired or established 84 of 477 foreign affiliates in the United Kingdom in 1998, the largest single-country figure. These new MOFAs in the United Kingdom accounted for the largest share (44 percent) of the gross product of all new MOFAs in 1998, the latest figure available from BEA. Other key locations for new U.S. affiliates in 1998 were Canada (38), Germany (36), the Netherlands (36), and France (27).

that complements or expands the parents' capabilities.

As a region, majority-owned European subsidiaries of American companies performed $10.6 billion (71 percent) of overseas R&D in 1998, the highest regional share. (See first data column in text table 4-19.) Canadian subsidiaries had a 12 percent share in 1998 but more than doubled R&D spending over 1994–98. On the other hand, Japanese subsidiaries performed 7 percent of U.S.-owned R&D abroad in 1998, down from a 10 percent share in 1994, reflecting the impact of the decade-long recession in that Asian economy. In fact, Canadian subsidiaries have been spending more than the Japanese units on R&D activities since 1996, something that had not happened since 1982. (See appendix table 4-48.)

According to the BEA data, about three-fourths of all R&D performed overseas by majority-owned affiliates in 1998 was undertaken in four manufacturing sectors: transportation equipment (30 percent), chemicals (27 percent), industrial machinery, including computers (7 percent), and electronic equipment and components, except computers (8 percent). (See text table 4-19.) Almost one-fourth of the $4 billion spent by majority-owned U.S. affiliates overseas in chemicals research (which includes pharmaceuticals and some biotechnology research) was performed in the United Kingdom; another 16 percent was performed in France.

On the other hand, of the $4.5 billion in automotive and other transportation equipment research overseas in 1998, 42 percent was performed in Germany and another 21 percent in Canada. This is not surprising, given the strong presence of American automobile factories and related technical centers in both countries. For industrial machinery, 31 percent of research abroad was performed in the United Kingdom and 22 percent in Germany. For electronic equipment, the countries with the largest shares were Germany (16 percent) and Japan (11 percent).

Text table 4-19.
R&D performed overseas by majority-owned foreign affiliates of U.S. parent companies, by SIC industry of affiliate and country: 1998
(Millions of U.S. dollars)

		Manufacturing					
Country	All industries	Total	Chemicals	Industrial machinery	Electronic equipment	Transportation equipment	Non-manufacturing
Total	14,986	12,746	4,002	1,116	1,212	4,465	2,240
Canada	1,771	1,569	395	23	124	917	202
Europe	10,580	9,154	2,988	874	724	3,084	1,426
Belgium	326	232	173	3	5	15	94
France	1,321	1,143	656	75	52	151	178
Germany	3,042	2,908	258	250	194	1,872	134
Italy	586	521	275	50	71	60	65
Netherlands	501	301	D	9	61	63	200
Spain	198	181	75	8	41	45	17
Sweden	448	385	D	23	8	D	63
Switzerland	234	164	35	66	17	0	70
United Kingdom	3,144	2,610	956	342	104	D	534
Rest of Europe	780	709	D	48	171	D	71
Asia and Pacific	1,690	1,267	445	162	237	139	423
Australia	302	240	54	9	1	D	62
Japan	1,030	722	317	76	132	5	308
Rest of Asia/Pacific	358	305	74	77	104	D	53
Western hemisphere	753	662	137	18	119	322	91
Brazil	448	435	72	13	D	D	13
Mexico	191	140	21	5	D	D	51
Middle East (Israel)	157	62	13	D	8	0	95
Africa	35	32	23	D	—	3	3

SIC = Standard Industrial Classification System; D = withheld to avoid disclosing operations of individual companies; — = less than $500,000

NOTES: Data are for majority-owned (more than 50% ownership) non-bank affiliates of nonbank U.S parents by SIC industry of affiliate. Data include expenditures for R&D conducted by foreign affiliates, whether for themselves or for others under contract. Data exclude expenditures for R&D conducted by others for affiliates under contract. Industrial machinery includes computer equipment.

See also appendix table 4-48.

SOURCE: U.S. Bureau of Economic Analysis, *U.S. Direct Investment Abroad: Operations of U.S. Parent Companies and Their Foreign Affiliates,* Preliminary 1998 Estimates (Washington, DC, 2000).

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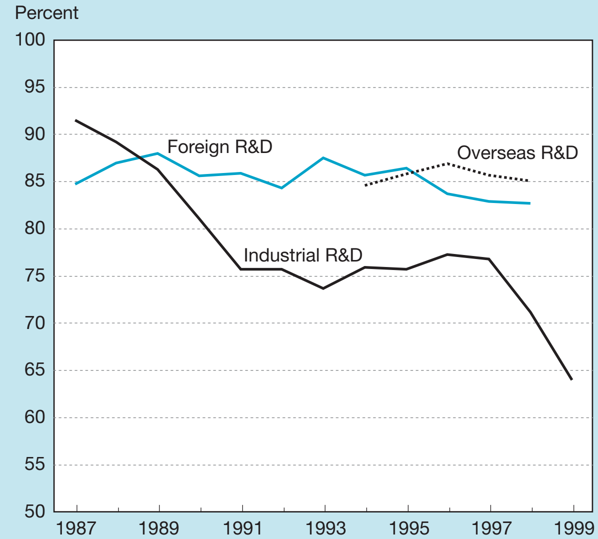
Industrial Structure of International R&D Spending and the IGRD Index

Manufacturing activity still dominates trends in total domestic, foreign, and overseas R&D spending, but such dominance has declined in recent years. Of these indicators, overseas R&D continue to have the heaviest concentration of manufacturing activity, followed by foreign R&D and total domestic industrial R&D. (See figure 4-38.)

Different industries dominate these three categories of R&D spending, revealing diverse technological and financial opportunities across U.S. borders. For example, 27 percent of R&D spending by foreign affiliates of U.S. companies was performed in transportation equipment, the highest proportion among all major R&D performing industries in 1998. (See figure 4-39 and appendix table 4-52.) However, this proportion is more than twice its 12 percent share of foreign R&D spending in the United States. On the other hand, chemicals research, which includes pharmaceuticals and some biotechnology, represented 33 percent of foreign R&D in the United States, twice its 17 percent overseas R&D share. Furthermore, the proportion of chemicals R&D in either foreign or overseas R&D spending is higher than its domestic company-funded R&D share of 13 percent, reflecting a high degree of globalization of R&D activity in this industry.

Another interesting pair of industries is computer manufacturing and information services (software publishing and data processing services). They represent the manufacturing

Figure 4-38.
Manufacturing shares in foreign, overseas, and total domestic industrial R&D



NOTES: Foreign R&D refers to R&D performed in the U.S. by United States affiliates of foreign parent companies. Overseas R&D refers to R&D performed abroad by foreign affiliates of U.S. parent companies. The industrial classification system used in industrial R&D and foreign R&D data changed from SIC to NAICS in 1997.

See appendix tables 4-31, 4-48, and 4-50.

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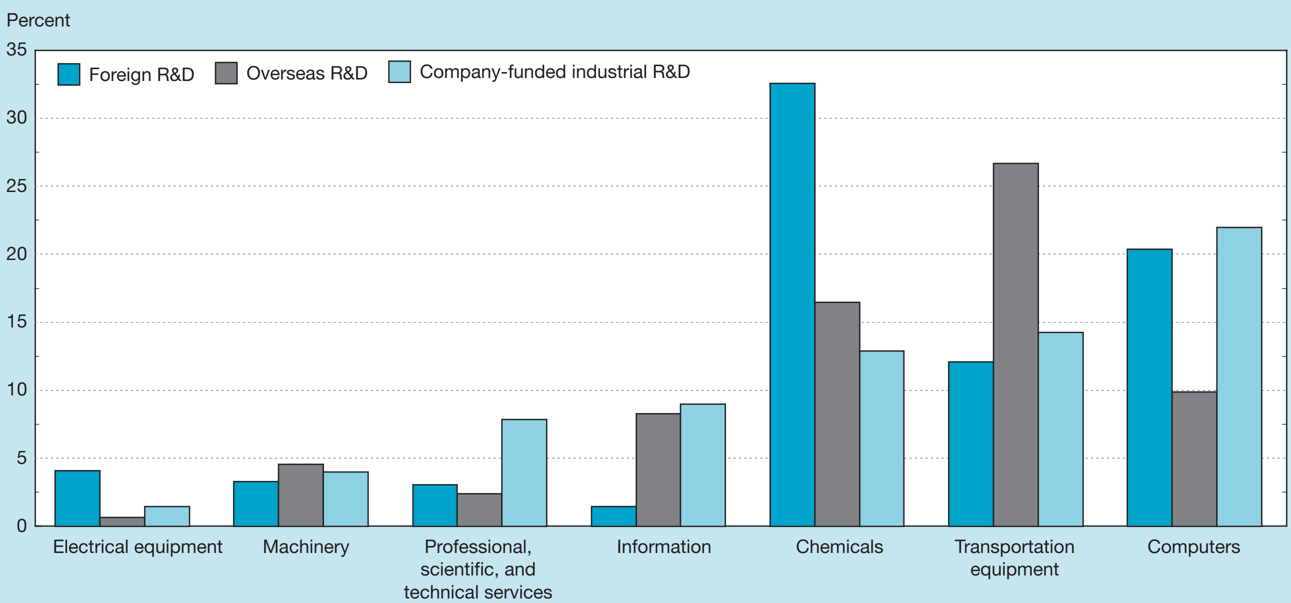
Figure 4-39.
Share of selected industries in foreign, overseas, and company-funded industrial R&D in the United States: 1998



NOTES: Foreign R&D refers to R&D performed in the United States by U.S. affiliates of foreign parent companies. Overseas R&D refers to R&D performed abroad by foreign affiliates of U.S. parent companies. The seven industries in this figure account for 77 percent, 69 percent, and 72 percent of foreign, overseas, and domestic company-funded R&D, respectively.

See appendix table 4-52.

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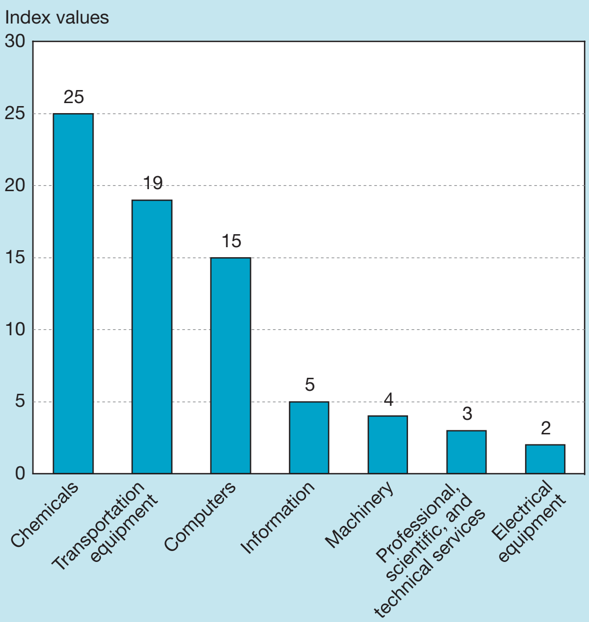
and services sides, respectively, of information technology activity. Remarkably, the share of information services in R&D spending abroad (8.3 percent) is five times larger than that industry's foreign R&D share (1.5 percent) in 1998. The opposite is true for computer and electronic products. The computer industry accounts for 20 percent of total foreign R&D in the United States, twice as large as its 10 percent share in R&D funds spent abroad. However, more data based on the newly established NAICS classification system would be needed over time to form a more accurate picture of the R&D flows in these two components of IT R&D.

Another measure of the degree of globalization of R&D activity is obtained by combining these R&D spending shares. Specifically, the Industrial Globalization R&D (IGRD) index is defined as the average of foreign and overseas R&D spending shares for a given industry.[84] This average indicates how open an industrial innovation system is to R&D flows, not unlike the sum of exports and imports, which quantifies the openness of national economies to the flow of goods. By this measure, chemical manufacturing in the U.S. exhibit the highest degree of internationalization with an IGRD index of 25, followed by transportation equipment (19), and computer manufacturing (15). (See figure 4-40.)

Several implications may be drawn from this indicator. An industry with a high IGRD index may be less constrained by national R&D expenditure trends. Furthermore, such an industry is more likely to have the institutional setup required to take advantage of technological opportunities elsewhere. The index could be used in conjunction with other international S&T indicators discussed in this volume, including bibliometric indicators, foreign-origin patents, international alliances and R&D facilities, and high-technology trade.[85]

[84]In principle, the IGRD index has a range of [0, 100]. However, reasonable index values for R&D-intensive industries in advanced economies are not likely to exceed or even be close to 50.

Figure 4-40.
Industrial Globalization R&D index for selected U.S. industries



NOTE: The Industrial Globalization R&D (IGRD) index is the average of foreign and overseas R&D spending shares for a given industry.

See appendix table 4-52. *Science & Engineering Indicators – 2002*

Conclusion

A resurgence in R&D investment in the United States in the mid-1990s has continued through to the beginning of 2000. A prosperous economy invigorated companies in both the manufacturing and service sectors, enabling them to allocate more resources toward the discovery of new knowledge and the application of that knowledge toward the development of new products, processes, and services. An upsurge in innovation is further contributing to a buoyant economy.

At the same time that the private sector's role in maintaining the health of U.S. R&D enterprise has been expanding, the Federal Government's contribution has been receding, as the Federal share has become less prominent in both the funding and the performance of R&D. Similar developments have been seen in many countries throughout the world. As a result of these two divergent funding trends in the United States, the composition of the nation's R&D investment is slowly shifting. For example, a growing percentage of the nation's R&D total has been directed toward nondefense activities.

Concurrent with these broad patterns of change, the locus of R&D activities is also shifting as a reflection of broad technological changes and new scientific research opportunities. For example, a growing amount of industrial R&D is now undertaken in services (versus manufacturing) industries, and much of the industry R&D growth has been in biotechnology and information technology. Reflecting the political reality of tremendous increases in research funding for NIH relative to other Federal agencies, the composition of these Federal funds has shifted markedly toward the life sciences during the past several years. Whereas industry has focused its R&D on new product development, the Federal Government historically has been the primary funding source for basic research activities.

As part of the changing composition of R&D activities, the organizational process of conducting R&D also has undergone substantial change. Greater reliance is being placed on the academic research community, and all sectors have expanded their participation in a variety of domestic and international partnerships both within and across sectors. The rapid rise in global R&D investments is evident from the expansion of industry's overseas R&D spending and the even more rapid rise in foreign firms' R&D spending in the United States. These domestic and foreign collaborations permit performers to pool and leverage resources, reduce costs, and share the risks associated with research activities. In addition, such alliances and international investments open a host of new scientific opportuni-

[85]See earlier sections in this chapter, as well as chapters 5 and 6 in this volume.

ties for R&D performers that undoubtedly will continue to redefine the R&D enterprise into the future.

Each of these developments creates further challenges in terms of data measurement and indicator improvement. Indeed, there are a number of specific areas of interest that could benefit from expanded data collections and analyses (National Research Council, 2000). Most notably, better information is needed on structural changes in industrial R&D (including research on the nature of R&D in the service sector and obtaining finer detail by industrial classification and geographic location). More extensive data could improve our understanding of the relationship between R&D and innovation to address the manner in which science and technology are transferred among firms and transformed into new processes and products. Fuller investigations and tracking of the apparent increase in the web of partnerships among firms, universities, and Federal agencies and laboratories in conducting R&D are warranted, as is more research on the extent and role of multidisciplinary research in science and engineering. Both of these latter topics, research that involves multiple partners and multiple fields, illustrate directly the growing complexities that characterize the R&D enterprise.

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